Appendix H

Interagency Coordination Team/ Studies for the Environmental Impact Statement

APPENDIX H
INTERAGENCY COORDINATION TEAM/STUDIES FOR THE ENVIRONMENTAL IMPACT STATEMENT

An Interagency Coordination Team (ICT) was established in 1995 to help the USACE accomplish the goal of developing scientific investigations to address environmental concerns raised by resource agencies and environmental groups. The Charter, which describes the goals of the ICT, and the membership of the ICT are provided below.

The ICT met for the first time in February 1995 and has met at scheduled intervals throughout the project. This includes 27 ICT meetings, four Modeling Workshops, seven DMMP Workshops, and one Cost Analysis Workshop. The ICT 1) has assisted the USACE in the development and implementation of the scopes of work for the scientific investigations; 2) has reviewed drafts of the scientific investigations, the DMMP, and FEIS; and 3) will provide a forum for continued coordination on the preferred alternative (DMMP) through the life of the project and provide advice on modifying management plans for the placement areas. Determination of the studies to be performed was normally by consensus. On the rare occasions when consensus could not be achieved, a majority of the voting members allowed for a decision.

ICT CHARTER

- Identify environmental concerns associated with GIWW in Laguna Madre
- Develop scopes of work needed to address environmental concerns
- Ensure effective team work among State and Federal agencies
- Contribute to and expedite completion of the Dredged Material Management Plan and Environmental Assessment for the GIWW

MEMBERS

Federal Agency Voting Member Agencies (1 vote per agency)

National Marine Fisheries Service	Mr. Rusty Swafford
U.S. Fish and Wildlife Service	Ms. Pat Clements
US Environmental Protection Agency	Ms. Barbara Keeler Mr. Mike Jansky
U. S. Army Corps of Engineers	Ms. Carolyn Murphy Mr. Joe J. Hrametz Dr. Terry Roberts Mr. Robert Hauch

State Agency Voting Member Agencies (1 vote per agency)

Texas Commission on Environmental Quality	Mr. Mark Fisher
Texas Parks and Wildlife Department	Mr. Ismael "Smiley" Nava Mr. Rollin MacRae
Texas Department of Transportation	Mr. Raul Cantu
Texas General Land Office	Mr. Tom Calnan
Texas Water Development Board	Mr. Raymond Mathews

Advisory, non-voting Members

Padre Island National Seashore	Mr. Darrell Echols
Coastal Bend Bays & Estuaries Program	Mr. Leo Trevino

Experts were invited as needed and meetings of the ICT could be attended by non-members but they were not allowed to speak unless invited. Workgroup meeting were not open to the public to allow for an unencumbered full and frank discussion among the ICT members.

A number of studies were contracted by the USACE, and one by the EPA, to provide the ICT with information for its use in providing input on the DMMP and for use in preparing the FEIS. These studies are summarized below. The full text of all of the studies can be found on the Galveston District website, (www.swg.usace.army.mil).

SPECIAL STUDIES

REVIEW OF INFORMATION CONCERNING WATER AND SEDIMENT QUALITY AND TISSUE CHEMISTRY

In 1995, the ICT expressed concern that objective decisions about the fate and effects of dredging and dredged material placement may be based on insufficient information. Specifically, the ICT wanted to determine the availability of water and sediment quality and tissue burden information in order to determine data gaps and initiate studies, if necessary.

A review of available information and historical studies was conducted (EH&A, 1995b) to answer these questions. A list of 56 contacts, representing 22 agencies or organizations, was compiled. Each person on the list was contacted by phone or in person to request available information. All information collected was reviewed, and an assessment of any data gaps was made. The various studies were summarized and separated into two groups: studies directly pertinent to the purpose of the review and incidental studies that, while not pertinent to the purpose of the review, might be of interest to the ICT. Study reviews and data gaps were discussed and appropriate station locations were mapped. In general, EH&A (1995b) determined that sufficient water and sediment quality data are available to analyze for areal and temporal trends in the Laguna Madre. Although very little tissue data for trend analysis was available, raw tissue data are not necessarily pertinent to concerns about dredging and dredged material placement; thus collection of additional tissue chemistry was not recommended. The primary data gap noted by the report was in toxicity data. Only one bioassay/bioaccumulation study had been conducted: at three stations near Baffin Bay. The report recommended that a tiered approach, as recommended by EPA/USACE (1991) be conducted in which existing data would be examined and reduced to determine whether there was a cause for concern. If a cause for concern were identified by this analysis, the report recommended that maintenance material samples be collected for bioassay and bioaccumulation studies (which would also involve water, elutriate, and sediment chemistry analyses). The data generated plus currently available information should be sufficient to allow an adequate characterization of the Laguna Madre relative to all but the physical impacts of dredging and dredged material placement.

DATA REDUCTION AND ANALYSIS: WATER AND SEDIMENT QUALITY AND TISSUE CHEMISTRY

In 1997, a reduction and analysis of the data sets identified by EH&A (1995b), which resulted in EH&A (1997a). Only data sets of sufficient size for areal and/or trend analysis were chosen. These included three sets of water data (TCEQ Surface Water Quality Monitoring [SWQM] and Special Studies, USACE Dredging History Database Management System, and TWDB Coastal Data System), five sets of sediment data (TCEQ, USACE, FWS Corpus Christi Bay Complex Study (CCBCS), National Oceanic and Atmospheric Administration [NOAA] Status and Trends, and EPA Environmental Monitoring and Assessment Program [EMAP]). Only the USACE database contained appreciable elutriate data. The TCEQ, CCBCS, and EMAP tissue chemistry data sets were examined to determine whether they were sufficient for analysis, but only the CCBCS data were sufficient for analysis.

Prior to analysis, all data were put into a format similar to that of the TCEQ SWQM STORET (Storage and Retrieval database) code format. The data sets were then subjected to trend analysis, both areal and temporal. Comparison to baseline data was ruled out as an analysis technique because of the extreme variability in estuarine systems which makes it difficult to separate impacts from background noise. Both types of trend analyses were included because of the variety of sources, although single-event data sets (e.g., CCBCS) could only be used for areal trend analyses. Areal trend analysis is useful for spotting point sources of pollution (e.g., a discharge source), whereas temporal analysis provides information on area-wide increases or decreases in pollutant concentrations with time. To conduct the analyses, the Laguna Madre was divided into roughly 3-mile sections throughout the entire ULM and LLM, the Baffin Bay Complex, and Arroyo Colorado. Breakdowns within the segment, where potential sources of pollution were noted, were discussed in the report (EH&A, 1997a). In all, data from 383 stations in the Laguna Madre, 141 stations in the Baffin Bay Complex, and 32 from the Arroyo Colorado were included in the analysis. All parameters for which sufficient data were available were included in the trend analyses. Because of unknown differences in collection techniques, chemical analysis techniques, detection limits, etc., it was determined that all trend analyses would be carried out within data sets and data sets would not be combined for analysis. While this reduced the number of possible analyses, it allowed increased confidence in the analyses that were conducted.

The data sets reduced and analyzed by EH&A (1997a) provided a broad-scale water and sediment quality characterization of the Laguna Madre. Some trends were evident in the evaluation of the data: higher concentrations of sediment metals at certain stations within the ULM and Baffin Bay complex, decreasing concentrations of sediment metals and total suspended solids (TSS) or total suspended matter (these terms are used interchangeably in the FEIS) with distance along the Arroyo Colorado, and larger ranges of values around the Port Mansfield Channel and Port Isabel. The report noted that these may reflect areas for concern or may simply be an artifact of non-replicated sampling, small ranges of concentration shifts, or variances in the number of samples per segment. While EH&A (1997a) found few trends among the data examined for this report, they noted that several areas might indicate causes for concern: the Arroyo Colorado (total dissolved solids (TDS), TSS, volatile solids in water; total organic carbon (TOC) in sediment; metals, chlordane, and DDT in tissue), Baffin Bay (dissolved metals in water; chromium, copper, and lead in sediments), parts of the LLM near Port Mansfield (TOC and metals in water), and near Port Isabel (metals in water and sediment), in addition to the samples from 1993 in the ULM.

CHARACTERIZATION OF DREDGED MATERIAL/CONTAMINANT ASSESSMENT

After a review of EH&A (1997a), it was determined that additional data collection, including water, sediment, and elutriate chemical analyses plus bioassays and bioaccumulation studies, would be appropriate. The EPA, a member of the ICT, financed a study (Lee Wilson and Associates (LWA), 1998a; EH&A, 1998a), with funds available from their Ocean Program, to conduct chemical analyses of water, sediment, and elutriate samples from 26 stations in the GIWW throughout the Laguna Madre and on samples from reference stations, including grain size analysis for the sediments, primarily to determine whether maintenance material would be suitable for ocean placement. Additionally, solid phase bioassays and bioaccumulation studies were conducted on sediment from six test stations, on Reference Control sediment, on a True Control (clean beach sand), and archive samples. Station locations were based on a review of USACE maintenance dredging records for the GIWW through the Laguna Madre from 1946 through 1995. Also considered were the potential for contamination (EH&A, 1998a), past and ongoing sampling efforts funded by the ICT and others, potential locations for beneficial uses of dredged material from the GIWW, and general geographic coverage of the GIWW through the Laguna Madre. Stations in the LLM ranged from LM20, near Port Isabel, to LM11 near the Land Cut, while ULM stations ranged from LM9, near the Land Cut to LM1, north of the J.F. Kennedy Causeway. Station LM10 was in the Land Cut, stations BA6 to BA4 were in the LLM, stations BA3 to BA1 were in the ULM, REF2 was offshore of the Brazos Island Harbor Channel, and REF1 was offshore of the Port Mansfield Channel. Analyses included metals, pesticides, total polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), phenols, TOC, total petroleum hydrocarbons (TPH) on all samples plus ammonia, total solids, total sulfide, and total volatile solids on sediment samples.

The following summarizes the results of these two studies:

1) Sediments in the Laguna Madre are primarily silts and fine sands with the finer sediments located in the lower half of the ULM and the upper half of the LLM, bracketing the Land Cut. In general, the sediments with the finer particles tend to have higher trace metal concentrations, sulfides, and ammonia.

2) TPH, phenols, PCBs and pesticides were below detection limits in all sediment samples. The only apparent trend was the increasing concentrations of metals, total sulfide, and ammonia-nitrogen in relation to increases in percent fines at the mouth of Baffin Bay south towards the Land Cut. There are no sediment quality standards on which to base expected impacts from bulk sediment analyses. However, LWA (1998a) used Effects Range Low (ERL) and Effects Range Medium (ERM), developed by Long et al. (1995) to gauge sediment concentrations. Based on comparisons to the ERLs and ERMs, arsenic in samples from stations LM-11, LM-14, and BA-6 and cadmium in samples from stations LM-8 and BA-4 could represent a cause for concern. However, some of these values appear to be outliers, since these values are more than 100 times other values and no toxicity was demonstrated by these sediments.

3) Results of chemical analyses on the water and elutriate samples indicate a potential cause for concern from concentrations of copper in elutriate samples that exceed the Texas Water Quality Standards (WQSs) for the protection of aquatic life. However, an analysis of the dilution required to achieve the WQSs indicated that the Limiting Permissible Concentration (LPC) for the water column is not exceeded (EPA/USACE, 1991).

4) Survival of organisms exposed to test sediments in the solid phase bioassays was not significantly different from survival of organisms exposed to the solid phase of the reference control, except for survival of the amphipod, *Ampelisca abdita*, exposed to sediments from Station BA-4. Even at Station BA-4, the difference between mean survival of test organisms and reference organisms was 20.5%, whereas any difference up to 20% is not considered indicative of potential environmental concern. However, notwithstanding that the toxicity exhibited by the solid phase was slight, the solid phase bioassay results indicated that the LPC for benthic toxicity is not met for *A. abdita* exposed to Station BA-4 sediments (EPA/USACE, 1991).

5) The mean concentrations of barium (stations BA-1, BA-5, and BA-6) and chromium (Station BA-5) in tissues of the polychaet, *Nereis virens*, were significantly higher than the respective average means in tissues from the Reference Control and True Control, but not archive organisms. Therefore, bioaccumulation is not shown by the data, only reduced depuration relative to control organisms. Uptake of barium at Station BA-1 was shown in the bent-nose clam, *Macoma nasuta*, relative to Reference Control tissues. Based on the examination of numerous factors, as required by the tiered approach in EPA/USACE (1991), significant ecological impacts would not be indicated by the results of the bioaccumulation study; i.e., bioaccumulation was only shown for barium in one species from one station. Moreover, barium has no Food and Drug Administration (FDA) Action Level because the physical and chemical properties of barium generally preclude the existence of the toxic soluble form under usual marine conditions (EPA, 1986). The FDA does not have a Guidance Document for barium.

Based on a strict interpretation of the guidance given in the Green Book, LWA (1998a) could not conclude that "reasonable assurance is given that significant ecological impacts could not result from the ocean placement of the test sediments," even though 1) only a small dilution will reduce the copper concentration to below the WQSs, 2) the toxicity exhibited by the solid phase was slight, and 3) the barium and chromium accumulation would not indicate a concern. However, had the LPC for benthic toxicity been met, the conclusion that significant ecological impacts would not likely result from the ocean placement of the test sediments would have been justified. Therefore, it would appear that additional solid phase bioassays with sediment from Station BA-4 will be necessary to determine the acceptability of Station BA-4 sediment for ocean placement. For placement in the Laguna Madre, the bioassays are conservative in that sandy open-ocean material was used as the Reference, not finer Laguna Madre sediments.

DEPTH MEASUREMENT AND BOTTOM CLASSIFICATION

To provide input into the hydrodynamic/sediment transport model and the seagrass model, the ICT recommended a study (USACE, 1998) funded and implemented by the USACE to generate detailed bathymetric data and to identify and delineate bottom types, including different types of seagrasses, throughout the Laguna Madre. In April and May 1995, hyperspectral data were collected, using a system known as Compact Airborne Spectrographic Imager (CASI). The USACE (1998) notes that "hyperspectral imagery differs from earlier types of multispectral imagery in that it is comprised of a large number of spectral bands or spectral bands of small bandwidth, or both." The imagery collected for the project used 11 bands, each of relatively small bandwidth. A total of 109 flight line tracks were flown to collect imagery data and a global positioning system (GPS) capable of locating the airplane with a horizontal accuracy of 5 meters (m) was used to navigate the CASI Imager. With geometric correction of the data, pixel size, both along-track and cross-track, was computed to be 4 m^2. Bottom depth, from the CASI, was calibrated by field measurements collected in May through July 1995. Additionally, the CASI data were geo-corrected by use of SPOT (Systeme Probatoire pour l'Observation de la Terre) satellite imagery.

In addition to the requested bathymetry and bottom-type information, the study team determined that it was possible to determine concentrations of brown tide in the Laguna Madre and the land-water boundary with CASI imagery. Therefore, detailed maps of the Laguna Madre showing bottom depth, bottom type, land/water boundary, and brown tide concentrations were generated as the final output of the study and appended to the final report (USACE, 1998). The report notes that brown tide concentrations and land/water boundaries are dynamic; i.e., constantly changing. However, although the bottom type and bottom depth should be considered, the validity of these data have been questioned; thus they are not used in the FEIS.

REDUCTION, ANALYSIS, AND INTERPRETATION OF DATA COLLECTED IN THE LAGUNA MADRE BY CONRAD BLUCHER INSTITUTE, 1994–1998

In August 1994, the Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University-Corpus Christi (TAMU-CC), the Marine Science Institute of the University of Texas (UTMSI), and the Center for Coastal Studies (CCS) of TAMU-CC initiated a multi-disciplinary, multi-year study (the CBI Study), the first year of which was described in Brown and Kraus (1997) and Militello et al. (1997).

The CBI Study included the collection (and, originally, the reduction and interpretation) of the following types of data: current velocity, turbidity, salinity, pH, temperature, dissolved oxygen (DO), chlorophyll-a, incident and underwater light irradiance (photosynthetically active radiation, or PAR), TSS, particle-size distribution, and, for the October 1997–May 1998 data set, water-level data. These data were supplemented by water-level and wind measurements from Texas Coastal Ocean Observation Network (TCOON) platforms located at Port Isabel, Arroyo Colorado, and South Padre Island. The objectives of this multidisciplinary study were to assess water flow and sediment transport conditions and to identify possible modifications of the dredging practice to both reduce environmental impacts and to minimize the cost and frequency of dredging.

While the overall purpose of the CBI Study was to provide measurements that would yield information on the impacts from dredged material placement in the Laguna Madre and data necessary for the models that were being developed for the FEIS, the original locations of the platforms in the ULM and LLM were designed for other specific objectives relative to dredging activities:

1. encroachment of sediment on seagrass beds,
2. resuspension of sediment in dredged material placement areas,
3. reduction of light within the water column,
4. transport of dredged material back into the GIWW and loss of material from placement sites, and
5. cause-and-effect relations between hydrodynamic forcing and sediment movement.

CBI continued to collect data to better understand the hydrography and sediment transport in the Laguna Madre and to provide input into the hydrographic and sediment transport models being developed by the Waterways Experiment Station for use by the ICT and in preparation of the FEIS.

The CBI Study collected an enormous volume of measurements, but the project suffered from three interrelated problems: failure or questionable validity of portions of the data record, a consequence of the experimental nature of the equipment; lack of consistent data-recovery and pre-processing protocols; and substantial changes in personnel at CBI leading to discontinuity in staffing of the project. Previous reports developed in the CBI project, in addition to the two Year-1 reports cited above, include two data reports Brown (1997) and Ussery (1997, with an addendum, Ussery, 1998).

In April 1998, the reduction and interpretation of the data from the CBI Study was performed by PBS&J and Dr. George Ward. Therefore, all available data collected from fixed-platform stations installed and maintained by CBI for the period of September 1994 through May 1998 were retrieved, subjected to QA/QC analysis, and processed. The analysis of these processed data, including those discussed in the Year-1 reports, are presented in PBS&J/Ward (1999), which is a composite effort of many contributors, including the previous reports, from which text was used where appropriate. The work was subdivided according to geography, i.e., the ULM and LLM systems.

Because of the larger base of data used, the data interpretation in PBS&J/Ward (1999) is new, even with respect to the Year-1 data. During the QA/QC effort, data problems emerged that were not accounted for in the earlier reports of Brown and Kraus (1997), Brown (1997), and Militello et al. (1997). PBS&J/Ward (1999) does not, however, replace these earlier reports. Moreover, some of the chapters in Brown and Kraus (1997), Brown (1997), and Militello et al. (1997) concerned only first year activities and, thus, were not included in the scope of PBS&J/Ward (1999).

The focus of PBS&J/Ward (1999) was on hydrographic data; i.e., the digital records from:

1. acoustic Doppler velocimeter (ADV) – three components of current velocity,
2. electromagnetic current sensor – two horizontal components of current velocity,
3. conductivity – internally converted to salinity in practical salinity units, equivalent to parts per thousand),
4. temperature – degrees Celsius,
5. turbidity – measured by an optical backscattering probe and reported in NTUs (nephelometric turbidity units),
6. water level – high resolution variation in water-surface elevation derived from pressure measurement.

These hydrographic data sets were supplemented by additional data, including TSS determinations on water samples, field and laboratory measurements of salinity, and data logs from proximate TCOON platforms, particularly water level (tide) and meteorological observations (wind, pressure, air temperature).

The original platform instrument packages used for the Laguna Madre did not include water level, and ancillary environmental data were used, from proximate TCOON stations, which included water level but not a direct measurement of wave activity at the measurement platform. Later instrument packages (data collected after October 1997), pressure (i.e., water level) is included in the array. During this same re-instrumentation the earlier ADV current sensors were replaced with the electromagnetic sensors.

Observations reported in PBS&J/Ward (1999), relative to the data collection effort, are quoted below:

Data anomalies are an ubiquitous feature of these robotic data acquisition systems. While there is no way to avoid their occurrence, these anomalies will corrupt analyses of the data and must be eliminated before analysis.

Among the anomalies encountered in the data records from this project are data gaps, zero values, time discontinuities, anomalous or "freak" values, quantum jumps in the time history of a variable, and flatlines. Most of these required a degree of manual editing to detect and correct.

The data sets analyzed in the Year-1 reports contained undetected anomalies, which were expunged in PBS&J/Ward (1999).

In addition to the normal sources of anomalous records from an automated system, the data holdings suffered further from hardware problems in the data archive.

Because of the principle of diminishing returns, some unresolved anomalies remained in the files and were subjected to analysis, but these were in such a minority that corruption of the analysis was considered to be minimal.

From the analysis of the data, a number of conclusions were drawn in PBS&J/Ward (1999), as quoted below:

1. The annual wind roses are dominated by prevailing southeast winds from the Gulf of Mexico. There is year-to-year variation in the annual winds. Monthly wind roses display a shift from predominantly southeasterly wind regimes in summer to bimodal in winter, i.e., alternating southeasterly and northerly winds resulting from frontal passages.

2. Power spectra of wind are characterized by a prominent spike at exactly 1 cycle per day (cpd). This is the signal from the sea breeze. The sea breeze spike is present throughout the year, minimal during the winter months, and maximal in the period from June to September. The greatest sea breeze energy is in the east-west component, transverse to the coastline.

3. Several lower frequency signals, particularly around 3- and 6-day periodicities appear in the wind spectra for the fall through spring period, being maximal in winter. These are the result of frontal passages during the winter and equinoctial seasons. Most of the energy of the frontal-passage periodicities is in the north-south component.

4. Power spectra of water level in the study area contain energy deriving from both tides and winds, as well as longer period variation due to meteorology (notably, frontal passages). In the annual spectra, there are prominent peaks at approximate periods of 12, 12.4, 24 and 25.5 hrs. Wind forcing is responsible for the 24-hour spike, mainly the sea breeze. This conclusion is reinforced by the coherency between wind and water level at this period, and by the seasonal increase of the energy in the 24-hour signal, which is greatest during the summer.

5. The tidal semidiurnal and diurnal signals from the Gulf of Mexico are substantially filtered with passage through the inlets into the Laguna Madre. The semidiurnal tide is nearly eliminated from both the ULM and LLM, and is evident only as a minor peak in the annual power spectra. The diurnal tide is attenuated, but is detectable in the power spectra in both systems. Longer period water level variations, mainly the fortnightly associated with the cycle of lunar declination, and the seasonal semiannual variation, are the most important sources of regular water level variation, but they raise and lower the Laguna waters so slowly that their effect on currents is negligible.

6. The current measurements performed at the platforms offer a direct index to mechanisms that may have a role in mobilization and transport of sediment. The original instrumentation measured the three components, including the vertical. The most important data are the horizontal components of the current. The data for the vertical component appear spuriously large, and were given no further attention in this analysis.

7. The long-term statistics of measured currents indicate that each station exhibits a propensity for net flow. In the LLM, at both LLM1 and LLM2, there is a northward component in the net flow, which may be the result of a mean wind-driven circulation entering the LLM through Brazos Santiago and exiting through Port Mansfield

Channel. In the ULM, station ULM2 does not set north-south as one might anticipate from the geometry of the Laguna Madre, and as is exhibited by ULM3 farther south, but has a significant component directed into Baffin Bay. Station ULM1 in Corpus Christi Bay just north of Bulkhead Flats shows predominantly westerly currents, paralleling the trend of the south shoreline and the bayward margin of the Flats. Current speeds are lowest in the interior of the ULM, compared with Corpus Christi Bay (ULM1) and the LLM.

8. The energy in the power spectra of (horizontal) currents is greatest in the LLM at LLM1 and lowest in the ULM. The peaks in the power spectra are at solar diurnal, lunar diurnal, and semidiurnal periods, though the relative importance of these is highly variable from platform to platform.

9. There is considerable month-to-month variation in spectra at some of these stations, as well as year-to-year variation. Energy in the lower frequency (longer period) portion of the spectrum is more prominent during the winter months than in the summer and is more prominent in the ULM than in the LLM. This is the part of the spectrum that is dominated by meteorological forcing at 3 to 7 day periods, hence the prominence in the winter months and the greater influence in the ULM.

10. The detailed behavior of the current vector was analyzed by constructing monthly scatter plots and current roses. These are complementary plots that should be studied as companion diagrams. The scatter plots preserve all of the vector information of the individual measurements. The distribution of the data points can give a visual impression of the speed/direction variation of the data but are biased toward the extreme values, because the smaller currents are overplotted as a massive cluster. The rose on the other hand is a statistical summary in graphical format, in which currents are sorted into bins of directional and speed ranges. These diagrams are analyzed for:

    a. extent of bi-directionality,

    b. prevalence of noncompensating directions, indicating a net nonzero flow component,

    c. asymmetry in current speeds,

    d. prevalence of favorable axes versus more omnidirectional distributions, and

    e. alignment with physiographic constraints such as bathymetry or shoreline.

11. These vector displays disclosed that the currents do seem to exhibit movement along a preferred axis. This is consistent with the back-and-forth type of forcing typical of bays and estuaries, usually driven by tides, which produce the classical "current ellipse." However, in the Laguna Madre data, this behavior is much more complex. By a detailed study of a few stations per month selected from these data holdings, employing a special-purpose analysis to fit a "normal least squares" to the data by 25-hr-duration steps, we determined the following:

    a. There is more than one preferred axis at each of these platforms, presumably corresponding to modes of large-scale circulation.

    b. The circulation appears to be metastable, following a given preferred axis for a number of tidal cycles then shifting to another axis.

c. Shifts from one axis to another are more-or-less synchronous in different regions of the system, indicating a large-scale systemic shift from one circulation regime to another. The mechanism that forces this shift is not clear from the few months of data analyzed here.

d. In lower Corpus Christi Bay, i.e. at ULM1, one preferred axis is along a north-south trajectory, and the other is along a line about 50° east of north. The former corresponds to flow in and out of Bulkhead Flats, while the latter roughly parallels the shoreline (and bayward margin of Bulkhead Flats).

e. At the mouth of Baffin Bay, i.e. at ULM2, one preferred axis is 10° (i.e., 190°) east of north, approximately the axis of the GIWW, and the other is 50° east of north, the direction of the entrance to Baffin Bay.

f. In the LLM, at LLM1 there are two preferred axes, at 15° and 70° east of north, the former being the one identified by Brown and Kraus (1997) from their scatter plots. At least two axes are indicated at LLM2, at about 45° and 120° east of north.

12. Dredging contracts were active in the early months of the data collection. In the LLM, there is a tendency for higher TSS magnitudes during the dredging periods than prior to the contract or (1 year) after the contract. While dredging would appear to be a factor, there are clearly other processes operating, because the TSS magnitudes are nearly as large in spring of 1996 when no dredging was underway. In the ULM, there is no clear difference between "dredging" and "post-dredging" periods partly due to the fact that the contract dredging period, very early in the data collection, was not well sampled.

13. Two measures of suspended sediments were made in the data collection program. TSS was measured on water samples collected at 12-hour intervals, and turbidity was measured automatically at the same interval as the current measurements using an optical backscatter (OBS) sensor on the platform. The OBS was a bold experiment to determine sediment concentrations on the same fine time-resolution as the other robot measurements, which, if successful, would allow direct computation of several important parameters relating to sediment mobilization and transport. Because the OBS sensor is sensitive to biofouling, the data proved untrustworthy, and could not be used quantitatively in this study.

14. There is no clear association between current velocity and the surges of TSS. The statistical relation between the two is nil, however the majority of data are low current speeds and low TSS, whose lack of correlation dominates the statistics. There may be relations between extremes of current and extremes of TSS. Where there is an association, it seems to be more governed by current direction than current speed. Longer rises in TSS seem to be associated with a direction of current, e.g., a mean northward set accompanies the higher TSS values observed in the LLM during April–May 1996.

15. In the LLM, at LLM1, there is an association between wind speeds and TSS, with elevated TSS values during periods of sustained higher winds, notable July and August 1995, and April and May 1996, and clear correspondences between spikes of TSS and spikes in wind speed, especially for those wind spikes exceeding 12 m/s. This is also the case in Corpus Christi Bay, ULM1, though the values of TSS are lower than in the LLM, and the clearest association is for wind speed spikes

exceeding 14 m/s. In the ULM, there is no clear relation, though the TSS values are generally higher in summer of 1996 than summer of 1995, and wind speeds were also higher in 1996 than 1995.

16. In the Year-1 report, Brown and Kraus (1997) gave special attention to the reach of the GIWW crossing the LLM that for 50 years has exhibited high shoaling rates in a 3-mile subreach extending from Cullen Bay almost to Port Isabel, midway in which platform LLM1 was placed. From current vector scatter plots, Brown and Kraus (1997) identified a component of the current at an acute angle across the axis of the GIWW, and proposed that this cross-channel flow in association with the practice of disposing of the dredged material to either side of the GIWW is responsible for the high maintenance rates. The present analyses confirm that there is indeed a prominent cross-channel component of current in this reach of the GIWW in the direction identified by Brown and Kraus (1997). The present results indicate, however, that there is more than one preferred axis of this transport at this station, a second axis being directed almost perpendicular to the GIWW. Moreover, at each of the platform stations maintained during this study there is at least one mode of transport across the GIWW indicated in the current data.

17. In an earlier study of the high-maintenance reach of the GIWW, James, et al. (1977) inferred current trajectories from the patterns of turbidity in several LANDSAT images from the 1970's, and proposed that there was generally flow at an acute angle across the GIWW in the center of the high-dredging reach. This general trajectory of currents agrees with the directions inferred by Brown and Kraus (1997) from scatter plot current diagrams. It is the conclusion of the present study that this is only one of at least two preferred current directions, effecting cross-channel transport, and the current trajectory proposed by James et al. (1977) is based in part upon misinterpreting the patterns of shoals and seagrasses also visible in the LANDSAT image. This conclusion in no way undermines the inferred importance of the cross-channel transport as a factor in the high maintenance of this reach. It does underscore that cross-channel transport occurs more broadly and in other preferred directions in this vicinity. The solution, which might occur to some readers based upon the proposed current trajectory of James et al. (1977), of moving the present PAs 233 and 234 a short distance north or south to be out of the main cross-channel trajectory, would be ineffective.

The following specific recommendations were suggested for any future data collection efforts since many problems with data acquisition at the platform are in principle detectable and capable of correction if such early screening methods are employed; this, in turn, would reduce irrecoverable data loss:

1. that preliminary screening of the data be carried to identify quantum shifts in variables, time slips, and flatlines (especially zero values)
2. that field maintenance protocols include in situ measurements of the same variables monitored by the platform, e.g., current velocity, salinity, temperature.

PBS&J/Ward (1999) also noted that as many questions about the mechanisms of hydrography and sediment transport in the Laguna had been raised as answered, and additional work was recommended.

1. A surprising finding of this project is the existence of multiple preferred axes of current direction, and that these seem to evidence larger-scale metastable modes of circulation in the Laguna Madre and Corpus Christi Bay. Therefore, it was recommended that the type of analyses initiated in PBS&J/Ward (1999) for a selection of the data base be made more rigorous and be applied to the entire data base to better determine the nature of these circulation modes. These analyses should include companion data on meteorology and Gulf of Mexico hydrography, as potential trigger mechanisms for forcing the shift from one mode to another. This result would not only be of intrinsic scientific interest, but would be of potential practical value in at least two respects: a) identifying a hydrodynamic feature of the Laguna Madre that could serve as a suitable crucial test for validating hydrodynamic models; b) identifying the conditions under which favorable or adverse sediment transport occurs, thereby providing guidance to scheduling and methods of dredged material placement.

2. The OBS offered promising technology for detailed measurement of important sediment transport processes. That it failed in the present project only underscores the fact that this is new technology that will require additional effort to develop into a practical and reliable methodology. Recent experiments with transparent antibiofouling compounds by the staff at the Blucher Institute may indicate a way to control this problem. Therefore, it was recommended continued experimentation with the OBS at CBI.

3. The fact that there is no correlation between TSS and currents in either the ULM or the LLM, but there may be an association between extremes of wind and extremes of TSS, raises questions about the causal mechanism. The increases in TSS monitored at these platforms may be in response to sediment resuspended elsewhere in the system (perhaps increased windwave activity in the windward shallows) and transported into the platform area by local circulations. The fact the spikes in TSS seem to be more associated with the direction of current than the speed adds support to this interpretation. Additional analysis and modeling using the data collected in this program, supplemented by TCOON data and archival remote sensing, were recommended to better determine the processes leading to these surges in TSS.

4. Cross-channel currents in the high-maintenance reach of the LLM were confirmed. These can be a significant mechanism for transport of suspended sediment across the GIWW, where a proportion of the sediments will settle out in the deeper water, thus contributing to the shoaling in the channel. Brown and Kraus (1997) recommended placement of the dredged material from the high maintenance reaches, presently being placed in Areas 233 and 234, in confined or upland areas to prevent their transport back into the GIWW. In effect, this means stabilizing or abandoning these placement areas for future disposal. PBS&J/Ward (1999) concurred with this recommendation, noting that Morton et al. (1998) found shallow-water or subaerial placement areas to be less exposed to windwave remobilization and the GIWW reaches using such placement areas to be low-maintenance.

BENTHIC MACROINFAUNAL ANALYSIS OF DREDGED MATERIAL PLACEMENT AREAS IN THE LAGUNA MADRE

In spring 1996, a study was performed to monitor the benthic macroinfaunal community composition in the Laguna Madre to provide insight into the environmental impacts of the historic practice of open-water placement of dredged material (EH&A, 1998a). The objectives of the survey were to describe benthic community composition, and to quantify basic community characteristics such as species and individual abundance, diversity, and evenness. Benthic macroinfauna and sediment data were to be used to determine whether the placement of dredged material in the past had an adverse impact on the benthic resources of Laguna Madre.

The study characterized the benthic community, at two different times of the year, in and near six placement areas in both the ULM and LLM and at reference sites across the GIWW from the selected placement areas. The placement areas were selected to depict 1) heavy, moderate, and light usage and 2) deep, non-vegetated and shallow, vegetated habitats.

TABLE 1

BENTHIC COMMUNITY USE

	ULM	LLM
Low-Use Vegetated	PA 183A	PA 229
Low-Use Unvegetated	PA 183B	PA 236
Medium-Use Vegetated	PA 190	PA 214
Medium-Use Unvegetated	PA 192	PA 219
High-Use Vegetated	PA 197	PA 221
High-Use Unvegetated	PA 198	PA 234

In each placement area, two randomly selected stations were occupied in the northern third of the placement area (stations N1 and N2), the middle third (stations M1 and M2), and the southern third (stations S1 and S2). Additionally, two stations parallel to the longitudinal axis, north and south of the north-south midpoint were occupied for each placement area, at 250 feet, or more, from the non-GIWW edge of the placement area (stations MD1 and MD2). Seven reference stations were to be located directly across, and at roughly the same distance from, the GIWW as the placement area stations (RN1, RN2, RM1, RM2, RS1, RS2, and RMD).

For the spring sampling, benthic samples were collected at 47 stations arranged within the 11 placement areas during May 1996 for a total of 178 macroinfauna and sediment texture samples. For the fall sampling, benthic samples were collected at 49 stations during September 1996 for a total of 177 macroinfauna and sediment texture samples.

Grain-Size Data

Sediments in fall were generally similar to those sampled in the spring, except that the ULM stations contained slightly higher amounts of sand during the fall survey. None of the ULM placement area sediments contained gravel (shell hash); all 14 stations where gravel was reported were in the LLM.

In both the spring and fall surveys, sediments at stations within the placement areas (N1–S2) were similar in most cases to sediments at reference stations (RN1–RS2). However, relatively low percent sand was observed at stations within three placement areas in the spring and two in the fall. In contrast, the reference stations at one placement area in the spring, but not in the fall, were considerably finer than the placement area and near-placement area stations. While the low percent sand in the placement areas may indicate that past placement practices have resulted in changes from predominantly sand habitats to mostly silt-clay habitats, the changes between seasons also indicate a dynamic system.

Benthos

In the spring, a total of 35,086 individuals representing 396 taxa was identified from 178 discrete samples. Polychaetes comprised the majority of individuals and the greatest number of taxa. The most abundant species-level taxon collected was the polychaete *Prionospio heterobranchia*. The second most abundant species was the amphipod *Ampelisca abdita*. The taxon with the highest frequency occurrence was the polychaete, *Melinna maculata,* which was present at 42 of the 47 stations.

In the fall, a total of 26,015 individuals representing 308 taxa was identified from 177 discrete samples. This was roughly two-thirds the abundance observed in the spring survey, and represented a decrease that is typical for the fall season in the northern Gulf of Mexico region. Polychaetes comprised the majority of individuals and the greatest number of taxa. The most abundant species-level taxon collected was the polychaete *Exogone rolani*. The second most abundant species was the polychaete *Prionospio heterobranchia*. Oligochaeta (LPIL) constituted 28.3% of all individuals, but probably included more than one species. The taxon with the highest frequency of occurrence was *Exogone rolani*, which was present at 36 of the 49 stations. This species was not identified during the spring survey, possibly because new literature became available to distinguish this species from *E. dispar*, which was numerically dominant in the spring survey. Both *E. rolani* and *E. dispar* were found in the fall samples.

Community statistics by station in the spring reflect a high degree of dissimilarity between placement areas, but moderate similarity between stations in the various placement areas. For both the spring and fall, numerical classification of survey stations was interpreted at an 8-group level, delineated at levels of similarity from 23 to 75%, indicating a low degree of homogeneity among stations within groups. There were two multi-station groups, one two-station group and four single-station groups. Within the station groups, the stations were grouped mainly according to placement area. Two station groups included mainly LLM stations, and one contained essentially ULM stations except for one station. Station groups did not correspond closely to sediment types, but in some cases did relate to presence/absence of seagrasses: one LLM group contained no seagrasses, while the other large LLM group contained either *Halodule, Thalassia,* or *Syringodium* beds. However, the large ULM station group included both grassbed and non-grassbed stations.

Community statistics by station in the fall also reflect a high degree of dissimilarity between placement areas, but moderate similarity between stations in and near the various placement areas. The number of species censussed was generally higher in the LLM than in the ULM during fall 1996. This trend was also observed during the spring 1996 survey but was less distinct. Statistical comparison of taxa numbers by station determined that species abundance and species diversity was significantly lower during the fall than during the spring (<0.001 and <0.005, respectively). Overall, species richness values were extremely variable, but indicated the presence of a high-quality and uniformly distributed estuarine infaunal community. Species abundance and richness values and biomass levels were generally higher in the LLM.

One of the key items in the study was the direct comparison of in-placement area stations (N1–S2) to the concomitant reference stations (RN1–RS2). In general, there were few differences between N1–S2 versus RN1–RS2 at any given placement area, with the most similar stations in the multi-station groups being the N1–S2 stations and RN1–RS2 stations, at a given placement area.

The results of direct statistical comparisons using each site in the N1–S2 and RN1–RS2 stations as a replicate and the Student's t-test to compare these two station-sets at each placement area for the number of individuals and the number of taxa for the spring sampling period yielded only three sets of data (the number of taxa at PA 198 and the number of individuals at PAs 229 and 234 where there was a statistically significant difference between the placement area station (N1–S2) and the reference stations (RN1–RS2). The fall sampling period yielded only one set of data (the number of taxa at PA 221) where there was a statistically significant difference between N1–S2 and RN1–RS2. Based on these results for both the spring and fall data, it was concluded that there was no significant differences between placement area stations and their respective reference stations. Therefore, placement areas exhibited minimal impacts from dredged material placement practices. Infaunal taxa and individual abundances varied primarily with placement area location and presence or absence of seagrass beds.

While not always true, RMD and MD1–MD2 stations in both the spring and fall tended to separate from the in-placement area stations and the other reference stations, supporting the hypothesis that nearness or farness from the GIWW may play a role in benthos composition.

In the spring, classification of the 61 taxa was interpreted at a 4-group level. These groups were delineated at a 33% to 87% level of similarity, which indicated moderate heterogeneity among species groups. In the fall, classification of the 67 taxa was interpreted at a 5-group level. These groups were delineated at a 31% to 82% level of similarity, which indicated moderate heterogeneity among species groups. Species groups contained different combinations of taxa in the fall and spring surveys, most likely because of generally low similarity levels for both surveys. This suggests that habitat types are only moderately distinct.

Temporal Comparison

Dredged material placement activities in the area date back to at least 1950, with the most recent dredging and placement occurring in 1995 to 1996. When selected benthic macroinfaunal community parameters were compared, it appears that most stations within placement areas contained more abundant and diverse macroinfauna than do adjacent reference stations for the most recent placements. Five of six sites where dredged material was placed 2 years prior to the May 1996 benthic collection exhibited higher numbers of species, individuals, diversity, and evenness. PA 219, where reference station benthos were more abundant that benthos at stations within the placement area, was the only recently used placement area where the sediment texture within a placement area exhibited a significant shift from sand to clay. The high proportion of clay at the stations in the placement area could have produced lower infaunal abundances. Older placement areas generally contained less abundant and diverse benthos. Placement areas used as much as 13 years prior to May 1996 contained similar sediments at the reference and within-placement area stations. Reference station benthos in PA 183A, which contained seagrasses, were richer than placement area-station benthos. In PA 183B stations (unvegetated), the benthos were more abundant within the placement area than at the reference stations.

For another type of temporal analysis, species censussed in both the spring and fall surveys were classified with respect to their status as indicators of one of the following three stages of community succession:

Group I: Opportunistic species prevalent during early succession;

Group II: Intermediate species found in mid-succession habitats; and

Group III: Near-equilibrium species associated with relatively stable, less-disturbed habitats.

There were only minor differences between the spring and fall assemblages.

From an examination of these species groups, it was evident that succession Group I taxa generally were most abundant at stations sampled in the ULM. Succession Group II species were more ubiquitous and exhibited little correspondence with geographic location. Succession Group III species, on the other hand, were best represented at stations in the LLM.

In the spring data, there appeared to be a trend toward higher parameter numbers in the placement area stations versus the reference stations for recently used placement areas. However, the comparisons for the fall data show no clear differences in benthic community statistics at placement area and reference stations, with respect to either location (north-south trends) or elapsed time since the most recent dredging. The infaunal assemblages censussed in the fall were generally less diverse and less abundant than during the spring throughout the Laguna Madre. Generally, there were no patterns of sediment texture that would reflect impacts from placement activities: sediment distributions, like infaunal communities, appeared to vary independently of the location and age of previous dredged material placement, although there was a slight trend of decreasing sediment coarseness from north to south.

Composition of benthic assemblages reflected geographic rather than placement-related trends in both the spring and fall surveys indicated again that placement practices have had little influence on the composition of the benthic communities in the Laguna Madre.

Vegetation Comparison

At the request of the ICT, the data were re-examined using the criteria of whether seagrasses were actually found at the stations to define the category of each station. These categories were seagrass or vegetated, semi-vegetated, or non-vegetated. The following ten parameters were chosen for analysis: 1) number of taxa per replicate, 2) overall density of the benthos, 3) species diversity, 4) evenness, 5) species richness, 6) depth, 7) percent sand, 8) density of Group I organisms, 9) density of Group II organisms, and 10) density of Group III organisms.

The listing of comparisons is broken down three ways; by type of stations, by the amount of seagrass at the various stations, and ULM versus LLM, to try to help explain the results of the analyses.

Type of Station

Examining the data by station type, there was only one instance where there was a significant difference between N1–S2 stations and RN1–RS2 stations, and that was grain size. There are also few differences between stations MD1–MD2 and RMD, or between N1–S2 and MD1–MD2. The only stations with any consistent differences are RN1–RS2 versus RMD.

Another way of examining the results of the statistical analyses is to examine the number of hits that occurs for a particular type of examination. For example, as was noted above, each comparison actually represents the statistical analysis of the means of ten parameters. Therefore, each comparison allows the opportunity for ten instances of statistical significance and there was no parameter for which a significant difference was not observed in at least one comparison. In the case of N1–S2 versus RN1–RS2 comparisons, there were six data sets that were amenable to analysis and, therefore, the opportunity for 60 instances of significant difference (hits). Of these sixty opportunities, there were only five, or 8.3%, hits. The MD1–MD2 vs. RMD station comparisons and N1–S2 vs. MD1–MD2 station comparisons, only had 5.0% hits each. The RN1–RN2 versus RMD station comparisons, on the other hand, had 22% hits.

Amount of Seagrass

The number of hits increased dramatically when the amount of seagrass at stations is compared, as opposed to the locations of the stations in or out of placement areas. For example, the seagrass versus semi-vegetated station comparisons yielded 15.7% hits, the seagrass versus non-vegetated station comparisons yielded 29.3% hits, and semi-vegetated versus non-vegetated station comparisons yielded 25% hits. As is not surprising, depth was significantly different in eight of the 14 data sets amenable to analysis in the seagrass versus non-vegetated station comparisons. When non-vegetated stations are compared to stations with any amount of vegetation, the mean density of Group I organisms (opportunistic benthos) was significantly different over half (9 of 16) of the comparisons.

Upper Laguna Madre versus Lower Laguna Madre

The results presented for the ULM versus LLM yields 34.1% hits, and if only the all seagrass stations comparisons are examined, there are 55% hits. It is interesting that in the comparison of the ULM and LLM stations, the density of the near-equilibrium, Group III organisms, was significantly different in a majority of the comparisons whereas in the comparison of amount of vegetation at stations, the density of the opportunistic Group I organisms was significantly different in a majority of the comparisons and Group I density was consistently higher in seagrass stations than in non-vegetated stations.

In general the results of the ULM versus LLM comparisons tend to support the conclusions that composition of benthic assemblages reflected geographic rather than placement-related trends in fall 1996. These patterns were very similar to those observed for the spring survey and indicated again that placement practices have had little influence on the composition of the benthic communities in the Laguna Madre.

Summary

Few clear distinctions exist in sediment texture or benthic macroinfauna that would indicate habitat differences caused by placement practices. Neither the spring nor fall data show any clear differences in benthic community statistics at placement area and reference stations, with respect to either location (north-south trends) or elapsed time since the most recent dredging. The infaunal assemblages censussed during September through October 1996 were generally less diverse and less abundant than during the spring throughout the Laguna Madre. In addition, there were no patterns of sediment texture that would reflect impacts, from placement activities: sediment distributions – like infaunal communities appeared to vary independently of the location and age of previous dredged material placement, although there was a slight trend of decreasing sediment coarseness from north to south.

EFFECTS OF OPEN-WATER DREDGED MATERIAL PLACEMENT ON HABITAT UTILIZATION BY FISHERY AND FORAGE ORGANISMS

The USACE contracted with the NMFS to conduct a study (Sheridan, 1999) to determine whether open-water placement of maintenance material from the GIWW in the Laguna Madre had temporal and/or spatial effects on 1) seagrass habitats, 2) the use of these habitats by fishery and forage organisms, and 3) overall system productivity. The study was conducted on three placement areas in the LLM (PAs 211, 221, and 222) and three in the ULM (PAs 187, 194, 197) that had been subjected to maintenance material placement in late 1994 and early 1995. Three habitats were examined at each placement area: 1) subtidal dredged material deposits at the center of the placement areas that were devoid of seagrasses at the beginning of the study (Maximum Impact Habitat); 2) seagrass areas within approximately 16.5 feet of the outward edge of the dredged material, where turbidity was expected to be high (Minimum Impact Habitat); and seagrass beds at least 3,300 feet from the placement area (Natural Seagrass Habitat). Five randomly placed replicate sites within each Habitat were sampled in September 1995, April and September 1996, May and September 1997, and April 1998. Additionally, at PA 194, an additional five replicates were taken at approximately 33 to 49 feet and 330 to 345 feet from the edge of the Maximum Impact Habitat to allow additional information to be gained relative to areal effects of maintenance material placement.

Parameters determined included the estimated area of the Maximum Impact Habitat; temperature, salinity, depth, and turbidity of the water; organic content and grain size of surface and subsurface sediment samples; shoot biomass, root/rhizome biomass, and coverage for seagrass samples; benthic infauna and epifauna in the upper 2 inches of sediment; and nekton densities. The data from each sampling period were analyzed with a two-way analysis of variance (ANOVA) to assess effects of locale (ULM or LLM) and Habitat, or with a one-way ANOVA to assess the effects of distance at PA 194.

The surveys of the unvegetated dredged material, originally ranging from 1,400 m^2 at PA 221 to 187,000 m^2 at PA 197, indicated that the soft-unvegetated areas generally decreased except for PA 197. The decreases were relatively rapid at PAs 211 and 221. Expected causes of the decreases at the five placement areas were resuspension of fine-grained material, compaction, and winnowing of fine-grained material yielding increased sediment stability. These latter two lead to revegetation. "The pooled effect for all 6 sites was a sharp drop (60% of initial) in non-vegetated mud area between September 1995 and April 1996, a relatively stable period of 18 months (probably due to spreading at PA 197), and final sharp drop (50% of remaining mud) in non-vegetated area between September 1997 and April 1998." The overall result was an apparent 75% reduction in the area of non-vegetated dredged material in a little over 3 years post-placement (dredging and placement occurred in January or March 1995). Silt content was always significantly higher in the LLM than in the ULM whereas clay content was always higher in the ULM than in the LLM, but the difference was not always significant. In the early part of the study there were occasional significant differences in organic content and sand or clay content that were related to Habitat but these differences declined with time, indicating a loss of fine-grained material from the Maximum Impact Habitat or sediment stabilization or both within 1.5 years of placement. With few exceptions, grain size was not significantly different between 0- to 2-inch samples and 2- to 4-inch samples in all three habitats.

Significant differences in temperature, salinity, and depth were almost always linked with locale, with higher values for these parameters in the ULM. Only the difference in salinity was large enough to likely impact species composition. Depth was generally, and expectedly, greater in the Natural Seagrass Habitat. Turbidity was only significantly greater in the Maximum Impact Habitat during the first two sampling periods, indicating that turbidity increases in non-vegetated areas of open-water placement areas. Turbidity also seemed to disappear after roughly 1.5 years.

Despite the consistently higher salinities and brown tide in the ULM, there were no consistent trends over time in seagrass community characteristics versus locale, with one exception. During four of the six sampling periods, the root:shoot ratio was significantly higher in the LLM, perhaps because of reduced light energy reaching the seagrasses due to the brown tide or because of higher salinity in the ULM. However, there were always significant differences relative to habitat: coverage, shoot and root biomass, and root:shoot ratios were always significantly less in the Maximum Impact

Habitat versus the Minimum Impact Habitat or the Natural Seagrass Habitat, except for root:shoot ratio in April 1998. Additionally, coverage in the Minimum Impact Habitat was significantly less than in the Natural Seagrass Habitat for 1.5 years after placement but the differences were minor (>90% coverage in both habitats at all times). Seagrass colonization of the Maximum Impact Habitats began between September 1995 and April 1996, when *Halodule wrightii* was found at all six placement areas. *Halodule wrightii* was the dominant seagrass in the study area and was found in all habitats except the Maximum Impact Habitat at PA 197 where *Halophila engelmannii* was the only seagrass found during the study. *Halophila engelmannii, Ruppia maritima*, and *Syringodium filiforme* were found regularly at some placement areas but *Thalassia testudinum* was rarely found in the study area.

Over 220 taxa, comprising 78,145 individual benthic organisms, were found in the sediments: 59% annelids, 34% non-decapod crustaceans, 6% mollusks, and 1% miscellaneous taxa. Both the Natural Seagrass Habitat and the Minimum Impact Habitat yielded roughly 2.5 times the number of benthic organisms as did the Maximum Impact Habitat. Neither annelid nor crustacean densities were related to locale but mollusk density was significantly higher in the ULM during four of the six sampling periods. However, these generalizations do not necessarily apply to the mean densities of individual species of any of the three taxonomic groups. The density patterns of the major benthic groups and individual species do not indicate recovery in the Maximum Impact Habitat, even after more than 3 years post-placement.

There were 79 taxa, comprising 20,636 individual organisms, in the nekton samples, with decapod crustaceans outnumbering fish by a factor of three. Both the Natural Seagrass Habitat and the Minimum Impact Habitat yielded about 2.5 times as many fish and about 9 times as many decapods as the Maximum Impact Habitat. The differences in fish densities in the Natural Seagrass Habitat and the Minimum Impact Habitat versus the Maximum Impact Habitat tended to decrease with time. Densities of total decapods were always significantly higher in both the Natural Seagrass Habitat and the Minimum Impact Habitat versus the Maximum Impact Habitat; these differences tended to be larger in the fall than in the spring; and there was a definite increase in decapod densities in the Maximum Impact Habitat in April 1998, which was likely related to the increased seagrass coverage. Total decapod densities were not consistently related to locale. Relations of individual species of fish and decapods were sometimes related to locale and/or habitat, with most habitat-related species being least abundant in the Maximum Impact Habitat.

The increased spatial coverage at PA 194 indicated basically that one could distinguish if samples were collected within the Maximum Impact Habitat or outside of it, although a few parameters indicated some intermediate values in the Minimum Impact Habitat, at about 33 to 49 feet distance versus the 330 to 345 feet distance, and in the Natural Seagrass Habitat.

The conclusions of the report were that the effects of dredged material placement at the Maximum Impact Habitat continue for at least 1.5 years for some parameters and beyond 3 years for others. Most of the originally non-vegetated dredged material that was likely to revegetate had revegetated after 3 years at five of the six sites (86% to 99% coverage). Some areas, because they were too shallow or too deep, are not likely to revegetate. The sixth site was PA 197, where revegetation had only been accomplished on 45% of the originally non-vegetated area. However, Sheridan (1999) states that complete revegetation may take at least 5 years. The parameters that appear to return to pre-placement values within 1.5 years include surface sediment organic content, surface sand/silt/clay ratios, and water column turbidity. Seagrass colonization of the Maximum Impact Habitat became noticeable a little over 2 years post-placement and became significant by a little over 3 years post-placement. With the colonization of the Maximum Impact Habitat by seagrasses (i.e., creation of Minimum Impact Habitat) increases in the densities of mobile macrofauna, such as fish and decapod crustaceans, can be expected. However, benthic food resources in the Maximum Impact Habitat had not shown signs of recovery even 3 years after placement activities had ceased. Dr. Sheridan notes that while assessment of the spatial scale of effects at PA 194 needed more samples to achieve sufficient power to detect differences, the data collected showed no consistent significant differences in most of the parameters (there were minor differences in temperature and salinity) at scales of 3, 33, 330, and 3,300 feet away from the Maximum Impact Habitat. The author also notes that one of the original purposes of the study was to compare sites that were typically affected by brown tide versus those that were not. Unfortunately, since brown tide only occurred at the three ULM stations and not at the three LLM stations, any comparisons were confounded by potential biogeographical differences between the ULM and LLM. However, since the distribution of benthic organisms was similar in this study to that found by earlier, pre-brown tide studies, the brown tide does not appear to have significantly affected benthic communities to any great extent, except for a decline in the bivalve *Mulinia lateralis*.

The author notes that "shallow submerged placement areas will revegetate with seagrasses and will attract macrofauna to levels comparable with natural seagrasses within 5 years. Development of comparable benthic communities will take...perhaps 5 to 10 years." Since dredging and placement occurs at some sites as often as every 2 to 3 years, the Maximum Impact Habitat at these placement areas will never recover. The author recommends that, since removal of maintenance material from the Laguna Madre system is the only mechanism that will allow total recovery, non-open water placement options (e.g., containment at leveed sites, offshore placement, or placement on emergent islands) should be used. Another option would be to place materials in deep water where redistribution by winds and currents is minimized.

At first glance there appear to be contradictions between the studies reported in a previous section (EH&A, 1998b) and this section (Sheridan, 1999). For instance, EH&A (1998b) found essentially no impacts from the placement of dredged material in a set of 12 placement areas, whereas Sheridan reported that some parameters might not be expected to recover from placement activities for 5 to 10 years. The differences between the results of the studies can be resolved by comparing the two studies. Sheridan (1999) looked only at placement areas which were used for placement from 1994 to 1995 and which had a bare mud zone, a vegetated zone within 16.5 feet of the bare zone leading to a natural seagrass zone 3,300 feet from the bare zone. EH&A (1998b) looked at only two such placement areas; the others either were not vegetated or had not been used recently. More importantly, EH&A made no distinction between the Maximum Impact Habitat and the Minimum Impact Habitat but compared stations within the placement area to reference stations on the other side of the GIWW from the placement area. All of Dr. Sheridan's stations were on the same side of the GIWW and the significant, long-term impacts he found were confined to the Maximum Impact Habitat. However, where direct comparisons can be made, there are similarities in the results of the two studies.

1. The MD1 and MD2 stations in EH&A (1998b) were intermediate between the Minimum Impact Habitat and the Natural Seagrass Habitat of Sheridan (1999) and do tend to separate out from the in-placement area stations (N1–S2). However, the equivalent reference station, RMD, also tended to separate out from the reference stations (RN1–RS2), which led EH&A (1998b) to conclude that distance from the GIWW may play a role in the benthic community.
2. Annelida was the dominant taxon in both spring and fall 1996 in both studies. *Prionospio heterobranchia* was in the top three most abundant species in both seasons in 1996 in both studies.
3. EH&A (1998b) reported that the number of species was generally higher in the LLM than in the ULM in fall 1996, and to a lesser degree in spring 1996, while Sheridan (1999) found significantly greater numbers of annelids and non-decapod crustaceans in the LLM in fall 1996 but not spring 1996. Mollusks did not follow this trend, being significantly more numerous in the ULM in spring 1996 (Sheridan, 1999), but mollusks accounted for only a small fraction of the number of organisms present in both spring and fall 1996.
4. As is typical for Gulf Coast estuaries, both studies found significantly more organisms in spring 1996 than in fall 1996, although the difference was less dramatic in Sheridan (1999).

SEDIMENT BUDGET ANALYSIS FOR LAGUNA MADRE, TEXAS

One of the persistent questions related to maintenance dredging of the GIWW through the Laguna Madre is the origin of the maintenance material. If the source of the maintenance material is eolian transport of barrier island material, storm washover, fluvial transport of runoff sediments from the mainland, shore erosion, or authigenic (formed in place) mineral production, then placement alternatives will have little or no impact on future dredging volumes. If, however, most of the maintenance material is reworked dredged material, placement alternatives that remove this material from the reworking cycle, could reduce the amount of maintenance dredging. The purpose of Morton et al. (1998) was to provide a sediment budget for the Laguna Madre which would provide an answer to the source of the maintenance material.

A number of physical processes were examined to provide input to the sediment budget study: wind characteristics, water level fluctuations, coastal storms, and relative sea level changes. The study noted that because of deposition on the east side and erosion on the west side, the Laguna Madre generally has an asymmetrical cross section that is characterized by smooth flats on the east side that gradually slope toward the lagoon center, and moderately steep and irregular slopes on the west side." Thus the lagoon appears to effectively trap sediment from both the eastern eolian transport and the western erosional transport. The report notes that from a morphological perspective, the Laguna Madre can be divided into four regions: Packery Channel to Baffin Bay, Baffin Bay to The Hole, The Hole to the Arroyo Colorado, and the Arroyo Colorado to Brazos Santiago Pass.

Eolian sediment supply (both saltation and suspension), supply via tidal inlets, storm washover, upland runoff, chemical precipitation, and biogenic sediment formation were all examined as inputs for sediment into the Laguna Madre. Eolian transport has been important in supplying sediment to the Laguna Madre, on both geologic and historic time scales. In fact, eolian transport accounts for 43% of the average annual sediment supply to the Laguna Madre. Supply via tidal inlets was the only other category with substantial sediment input into the Laguna, all from Brazos Santiago Pass (21%) and Port Mansfield Channel (17%). All of the other input mechanisms combined accounted for 19% of the average annual sediment supply to the Laguna Madre.

Sediment maps, past cores and grain size distribution studies, sediment dating studies, as well as several types of cores taken specifically for the Sediment Budget Project, were examined to develop the characteristics of Lagunal sediments to aid in the determination of reworking versus outside sources as the source of maintenance material. Using pre-GIWW engineering plans, as well as more recent data, Morton, et al. (1998) determined that the near-surface sediments in the ULM are sandy with abundant shell, while the LLM near-surface sediments are muddy with little shell. Below the Arroyo Colorado, Laguna Madre near-surface sediments are a thin veneer of muddy sediments that overlie Rio Grande deltaic deposits. The conclusion of the sediment budget calculations was that the "average annual volume of new sediment delivered to Laguna Madre...is...969,600 m^3." Of this, 44,320 m^3 makes its way into the GIWW. Over the past 45 years, the average annual maintenance dredging has been 1,659,429 m^3. Therefore, it was calculated (Morton et al., 1998, Table 1) that only 44,320 m^3/yr (or 2.7%) of the 1,659,429 m^3/yr is supplied into the Laguna Madre. This led to the conclusion that the majority (97.3%) of the maintenance material is from the re-working of existing Laguna Madre sediments.

Comparing the average sedimentation rate with average sea level rise on the south Texas coast, Morton et al., (1998) also determined that the Laguna Madre is not filling up, but rather is slowly being submerged. Because of the deposition on the eastern side and erosion on the westward side, as noted above, the Laguna Madre is also slowly moving westward.

The report used several techniques to examine the reworking of dredged material in the Laguna Madre. These included 1) past dredging records, both for original GIWW construction dredging and subsequent maintenance dredging; 2) examination of past maps and recent bathymetric examinations; 3) physical examination of existing placement areas, including comparison of sediment types and features from three types of cores collected during the present study, observations concerning island shapes, and types and location of surrounding vegetation; and 4) examination of in situ specific gravity, water content, and void ratio of sediments collected from a variety of placement areas, from the lagoon near the placement areas, and from the GIWW near the placement areas. These last parameters were used to evaluate volume losses of the dredged material after placement to determine how much of the material at the placement areas was original construction material, maintenance material, and/or material added to the placement areas from other sources. The conclusions drawn from all of these observations is that the material at the placement areas above the original Laguna Madre floor are residuals from the construction of the GIWW and neither maintenance material nor materials added from other sources. Another important aspect of this analysis is that major storms, such as Hurricanes Carla, Beulah, and Allen, cause increased shoaling in the GIWW for several years after the storm.

Three reaches of the GIWW were identified as having minimum historic maintenance dredging: one in the ULM and two in the LLM. The characteristics of the reaches are

1. sheltered by uplands with exposure to waves and currents limited to only one side of the placement area,
2. dredged material placed on broad flats that are subaerial much of the time or inundated by less than 1 foot of water,
3. located along a straight (no bend) reach of the GIWW, and
4. in a confined area of the Laguna Madre such that GIWW flow is accelerated, minimizing deposition and accelerating in-channel transport.

The report also discussed several approaches attempted in 1995 to reduce the transport of dredged material from placement areas. These included use of subaqueous berms and emergent berms and the planting of seagrasses. While maintenance material retention using the two berm techniques was better than current standard unconfined open lagoon placement, substantial erosion also occurred at the bermed areas. Seagrass plantings were found to provide no improvement over unconfined placement. The seagrasses did not survive because the planting area was too deep and wave and current forces were too strong.

The ultimate conclusion reached by this report is that the primary source of shoal material in the GIWW is internal reworking of sediments within the lagoon. Reworking is minimized where dredged material is placed on flats or extremely shallow water, but nearly all dredged material placed in deep water is reworked and either transported back into the GIWW or dispersed into surrounding areas of the lagoon. When the GIWW was first constructed, the drought period of the 1950s was occurring, the emergent sediments dried out, and the wind was the primary erosion factor. Subsequently, and especially for maintenance material, water has been the primary force eroding the placement areas and reworking the dredged material and other sediments in the lagoon.

HYDRODYNAMIC MODELS OF CIRCULATION AND SEDIMENT TRANSPORT IN THE LAGUNA MADRE

This study (Teeter et al., 2003) used sediment information and a numerical model to predict the effects of dredged material placement, resuspension, and dispersion on water column suspended sediment levels, especially in environmentally sensitive seagrass beds. The model study objective was to predict long-term (annual) dispersion of placed dredged material and its effect on water column concentrations and light conditions in the Laguna Madre.

The Laguna Madre, which consists of two shallow tidal bays, transected and connected by the GIWW, extends 117 miles from Corpus Christi Bay to Port Isabel, Texas, near the Mexican border. The average depth is about 3 feet. The total surface area is about 580 mi^2, of which 70 percent is covered by seagrass. Tidal currents and circulation are weak. Windwaves and wind stress play important roles in sediment resuspension and in material transport.

Since its completion in 1949, sediment dredging has been a part of routine GIWW maintenance. Dredging is typically performed on 23- to 60-month cycles, depending on the channel reach; the average total channel sedimentation rate is about 2.1 mcy per year, more than the natural sediment inputs to the system. GIWW construction formed mounds of lagoon sub-bottom sediments along the waterway, which have been subject to erosion. In addition, much of the maintenance material placed along the GIWW eventually is resuspended and dispersed. Channel maintenance materials are mainly fine-grained silts and clays less than 62 μm.

The basis of much environmental concern is that an appreciable area of the Lower Laguna Madre apparently became bare sometime between the seagrass survey in 1965 and the subsequent survey in 1974. The deepest area of the Lower Laguna Madre converted from vegetated to bare, while some Upper Laguna Madre areas converted from bare to vegetated. Speculation was that increased turbidity and decreased light penetrations resulting from dredged material placement and subsequent dispersion were the cause of the seagrass decline. A seagrass survey in 1988 showed no appreciable increase in bare-bottom areas.

Observations have shown that wave action is primary to the resuspension of sediments; therefore, the first step in wave modeling was to assess previous wave-prediction techniques by comparing the results predicted by use of these techniques with new field data. Waves observed in the Laguna Madre did not follow previous wind-wave relationships, possibly because of high wave-dissipation due to friction. Bottom friction, white-capping, and seagrass friction are involved in wave dissipation and are especially important in the Laguna Madre. Wave and wind measurements were analyzed and results used to develop a new wind-wave shear stress algorithm for the model system. The new algorithm is based on a partitioning of atmospheric shear stress. Expressions for atmospheric drag coefficient and depth-limited wave height and period were also developed.

Measurements made of suspended sediment concentrations, suspended floc-size distributions, and bed-material properties show suspended sediment concentrations vary both spatially and temporally and overall from about 5 to 500 mg/l. Bed sediments are sands over most of the Laguna Madre with some limited areas of fine-grained sediments. Measurement information from this study, from associated studies, and from previous studies was used to specify initial, boundary, sediment, and seagrass conditions in the model and to validate model performance.

Field measurements and laboratory experiments were conducted to develop information on settling, erosion, and depositional properties for use in the sediment model. In this study, sediment bed erodibility was the key factor under investigation. Erosion parameters were determined by erosion experiments and characterization tests on material from the system. Erosion experiments were performed on undisturbed box cores obtained from the Laguna Madre. Channel sediments were also used in the laboratory to create simulated dredged-material slurries. Slurry samples were allowed to settle and consolidate before erosion testing was begun.

Erodibility of dredged material depends upon the dredging and placement procedures as well as upon sediment properties. Field sampling was performed around a working dredge to obtain characteristics of the fluid mud - gravity underflow and the water-column plume formed by the discharge. The underflow extended 1,300 to 1,650 feet from the dredged material pipeline discharge point. Median fluid mud thicknesses were 18 inches, of which the top 60 percent was interpreted as underflow, and the remainder was deposit. A plume of 200 to 500 mg/l above ambient concentrations occurred above, but not much outside of, the underflow footprint.

The effect of suspended sediment concentration on floc settling rate due to flocculation was included in the model. Information on this process was obtained from the field and laboratory settling experiments. Field experiments were carried out to measure floc size on undisturbed suspensions; a limited number of underwater light and turbidity measurements were made in the field; laboratory settling experiments were performed, and several dozen water samples were collected, and their organic and calcium carbonate contents were determined.

Because it is very difficult to separate effects of dredged material resuspension by use of field data, the approach of this study was to apply a physics-based sediment model, with and without dredged material placement, to gauge the water-column TSM effects from placement area resuspension and thereby to eliminate the variability in other conditions. One purpose of model simulations was to provide suspended sediment time-series, at certain points within the system, to a Seagrass Productivity Modeling (SPM) team for seagrass growth assessment. Another purpose was to provide spatial distributions of water column impacts on suspension concentrations and on availability of light to seagrasses.

Two-dimensional, depth-averaged, numerical hydrodynamic and sediment transport models were developed and applied. The modeling effort was divided into estuarine circulation, wind-wave, and sediment components. Modeling was performed in two dimensions (2-D), depthaveraged, using the U.S. Army Corps' Surface Modeling System (SMS ©) and the TABS-MDS model. TABS-MDS is an enhanced version of the earlier RMA10-WES and RMA10 models that did not have sediment transport capability. The TABS-MDS was given new capabilities for this study.

The TABS-MDS model performs implicit finite-element solutions of the depth-averaged Navier-Stokes equations for turbulent flow. Model equations based on conservation of mass and momentum (shallow water wave equations) include non-linear advective and friction effects. The latest bathymetry was compiled and used to develop the model mesh. Assignment of model roughnesses was based on the sediment type, bed roughness features, depth, and the species of submersed aquatic vegetation. The effect of aquatic vegetation on hydraulic roughness was obtained from literature. Precipitation and evaporation were included.

Sediment grain-size distributions were discretized into one clay, two silt and one sand fractions for TABS-MDS model simulations. The TABS-MDS sediment model simulates erosion and deposition processes and includes bed processes such as consolidation and erodibility relationships for grain size composition and bed density. For a given erosion rate (mass per unit area), the model uses the dry density of the bed layers to compute the change in bed elevation. The model uses a layered bed structure to characterize the density and erodibility both horizontally and vertically in the bed.

During model adjustment, sediment parameters were adjusted in small steps about their estimated values and the response of the model observed. In this way, the combination of parameters that were physically reasonable and that minimize the differences between model and prototype data were determined. Model adjustment simulations lasted long enough to wash out the effects of initial conditions and to reach equilibrium concentrations with respect to water-mass residence times.

After the model adjustment, the ability of the model to predict suspended-sediment concentrations was quantified by comparing its data to field data. Suspended-sediment concentrations, channel deposition, and overall placement area (PA) erosion rates were used in the comparisons. The initial model scenarios included annual simulations with and without dredged material placement. Placement at six PA was simulated. Results were used to gauge water column impacts of the dredged material as it dispersed in the year following placement. Results from 26 locations, mostly in the Lower Laguna Madre, were also used in the SPM seagrass growth model.

Several plans for alternate PA locations were tested with the model. In the Lower Laguna Madre, PA 233 and 234 (located about 7.5 miles north of Port Isabel) have received the highest dredged material volumes in the Laguna Madre, and the adjacent channel area has long been identified as one of the major deposition and channel maintenance problems along the Texas GIWW. Tests were performed on the PAs being relocated in the model to the west into deeper water. Channel shoaling was reduced, and more material was retained with the proposed sites. A confined site configuration was also tested for the PAs but showed increased erosion because of higher currents caused by the confined PAs.

Slightly to the north, PA 232, which has shoaled up over the years, was moved, in the model, from the west to the east side of the GIWW. Model results indicated that in the new location channel shoaling was slightly decreased. However, subsequent investigation indicated that seagrass was growing at the proposed relocation site.

In the model, PAs 186 to 189, the Upper Laguna Madre, were combined into a site on the west side of the GIWW at a relatively deep area known as Emmord's Hole. The intent was to concentrate immediate water column impacts into an area that has no vegetation at the present time. During the month of placement, the model indicated that an area about 2,300 feet long would have TSM increased by 26 mg/l. During the subsequent 11 months, TSM increased by no more than 7 mg/l outside of Emmord's Hole.

AN INTEGRATIVE MODEL OF THE EFFECTS OF DISPOSAL ON SEAGRASS DISTRIBUTION AND PRODUCTIVITY IN THE LAGUNA MADRE

This report (Dunton et al., 2003) presents the results of an interdisciplinary collaborative effort to develop an integrative model for seagrass productivity in the Laguna Madre. One of the major components of this integrative model is the Laguna Madre Seagrass Model (LMSM) which was designed to interface with other component models described in this report, including carbon and nitrogen allocation, sediment diagenesis, and spectral irradiance and radiative transfer. Linkage with hydrodynamic and sediment transport models provided a potentially valuable management tool to assess the effects of maintenance dredging and the re-suspension of dredged material deposits on the seagrasses of Laguna Madre.

The development of the models described in this report required a substantial input of data for model calibration and when possible, verification. For the seagrass models, much of this data set was available from previously published studies (e.g. *Halodule wrightii*), but intensive field work, from April 1996 to December 1997, provided the additional data needed to develop the models presented in this report. Dunton et al. (2003) presents the results of these field investigations, which were conducted at 24 transect-survey sites (12 stations paired by seagrasses and bare bottom) and six permanent stations, to fill gaps in the knowledge of seagrass biology, variations in water column and sediment geochemistry, underwater irradiance, and the inherent optical properties of Laguna Madre waters.

Studies on seagrass biology included delineation of the photosynthesis vs. irradiance (P vs. I) relationships for *Syringodium filiforme*, which were used in developing the LMSM for this species (P vs. I relationships have been previously published for *Halodule wrightii* and *Thalassia testudinum*). In addition, density and above- and below- ground biomass of the three grass species were collected over variable temporal and spatial scales at 12 transect sites and three permanent stations in the Laguna Madre. Continuous measurements of photosynthetically active radiation (PAR) were also collected at the permanent sampling stations. Indices of carbon and nitrogen content were measured in leaves and below-ground tissues to provide data for the LMSM and allocation models for *Thalassia*.

Thousands of samples were analyzed in efforts to better understand the complex geochemical relationships occurring within Laguna Madre seagrass beds. Samples at 24 transect sites were collected; in addition, sediment chemistry was examined in detail from vertical profiles conducted at four additional stations. Results demonstrated that most sediments in Laguna Madre are sandy with a relatively narrow range in their physical and geochemical characteristics and that the diagenetic activity takes place in the upper few centimeters of sediment (in contrast to most estuarine siliciclastic muds). This work also demonstrated that the flux of ammonium from resuspended sediments (as occurs during dredging) can be substantial, thereby providing a large pulse of inorganic nitrogen that, it was hypothesized, might fuel phytoplankton blooms. This finding is important, since measurements of water inorganic nitrogen levels are generally low (<3 µm) throughout the Laguna Madre. Such low concentrations probably play an important role in regulating phytoplankton production, as reflected in water column chlorophyll levels that are <10 µg /L in the lower Laguna Madre.

Knowledge of the inherent optical properties (IOPs) of Laguna Madre waters is critical in developing a radiative transfer model to link with the LMSM. Strong relationships were observed between IOPs and total suspended solids (TSS). TSS is likely to contribute most to water column light attenuation during dredging events, which can result in significant reductions in both light quality and quantity. Declines in light-driven photosynthetic oxygen evolution can have serious effects on seagrass health. Sediment geochemical model simulations suggested that root zone fluxes of oxygen (produced during photosynthesis) were essential to maintaining non-toxic levels of sulfide. In addition, model results indicate that seagrass beds overlain with even modest (cm) amounts of dredged material can experience rapid increases in sulfide concentrations that can be sustained at toxic concentrations for several months.

The LMSM was developed for *Halodule, Syringodium, and Thalassia*. Of the three models, the LMSM was able to reproduce many features of a continuous nine-year data set for *Halodule*, mainly because the *Halodule* set contained a prolonged period of light stress (brown tide event) interspersed between two periods of favorable light climates. Simulations using worst-case light attenuation profiles show that the seagrasses are able to withstand short periods (one to two weeks) of very high water column light attenuation. However, under prolonged periods of low PAR (ca. 100 days or more) of even moderate levels of water column attenuation, model predictions indicate potentially dangerous decreases in plant biomass.

Dunton et al. (2003) produced an integrative and quantitative model that predicts the response of seagrasses to changes in their environment, particularly with respect to changes in light availability, based on extensive interdisciplinary field observations and experimental studies conducted over the past two years. Model simulations and in situ measurements of an actual dredging event strongly suggest that dredging operations are very likely to have a measurable negative impact on the health when (1) dredging activities occur over extended periods (weeks) when the plants are metabolically most active (spring through autumn), and (2) the dredging activity and/or placement of materials occurs within 0.6 mile of the grass bed.

The results of the LMSM depend, as does any model, upon a variety of inputs (chief among which are values for TSS) and assumptions that are used in the interpretation of simulation results. For example, the seagrass model was run at sites that were not immediately adjacent to placement areas. This was done to simulate the impact of placement on the Laguna Madre as a whole. The Seagrass Model addresses a representative area and can be applied at any location along the length of the Laguna Madre. Similarly, the hydrodynamic and sediment transport models cover the whole length of Upper and Lower Laguna Madre. Given such a wide spatial coverage in all three models, there will always be regions where differences occur between model output and observed data. The power of these models lies in providing information on long-term trends and large scale spatial patterns.

The authors noted that the output from the LMSM needs to be interpreted in the context of long term trends and large scale spatial patterns. They were confident that the LMSM performs well in this respect. The reports conclusions on dredging impacts to seagrasses include the results of additional model simulations based on data collected during actual dredging events (e.g. model verification study at PA 235) and in situ observations of seagrass response to chronic reductions in underwater light regimes.

The results of the production runs of the LMSM combine output from the WES Hydrodynamic and Sediment Transport models to provide suitable forcing conditions for the

Seagrass Biomass and Diagenesis Model. The WES model was designed to addressed a "worst case scenario" as defined by the members of the ICT. Placement occurred in the model on 1 April 1995 at six sites (three in the ULM and three in the LLM) with a total of 1.7 million tones (dry weight) of material being placed over a period of 24 hours. Sites for the seagrass model were located ¾ to 4.4 miles from the nearest placement area in the WES model. The results of the WES models and the Seagrass Model predict that at the sites simulated, the seagrasses survive the impacts of placement of dredged material with seagrass beds closer to actual placement sites being impacted to a greater extent than those further away. In interpreting the results from this model, the authors note that the reader needs to be aware that maintenance material is usually deposited over a period of approximately 1 week, and not in 24 hours. In addition, the total amount of material deposited in the model was approximately 50% greater than the average annual dredging in Laguna Madre and thus the simulation modeled an extreme case.

Modeled concentrations of TSS tend to be elevated during the spring and the fall, with lower values during the summer growth period. The time series of modeled underwater irradiance reflects the changes in the TSS concentration; low light levels occur during the spring and fall months and increase during the summer. Long-term trends in modeled TSS at the sites considered in the LMSM show little difference between dredging and non-dredging scenarios. This is partly due to the fact that sites for the seagrass model were chosen to examine large-scale, Laguna-wide impacts of placement. Simulations based on data collected at PA 235 were performed to examine the impact on seagrasses in close proximity (less than 0.6 mile) to a placement site.

Biomass at the *Halodule wrightii* model sites tended to increase and values at the end of the simulation were higher than those observed in Laguna Madre. The model predicted above-ground biomass values for *Thalassia testudinum* that generally lie between 100 and 150 gdw m^{-3}; these fall within the range of measured biomass in the Laguna Madre.

Root-zone HS^- concentrations are low except at a few sites in the upper Laguna Madre. Typical values predicted by the model are between 5 and 10 µm, though in the upper Laguna Madre concentrations can reach as high as 400 µm. For NH_4^+, the model predicts root-zone concentrations between 100 and 350 µm, which are within the range of measured values. Both the HS^- and NH_4^+ concentrations predicted by the model are not sufficient to significantly affect the growth and production of the plants, indicating that under the conditions of the production model, available irradiance is the dominant factor affecting seagrass growth and production.

The model assumes that the only factors contributing to attenuation of light in the water column are the water itself and TSS. The LMSM did not account for the effects of other factors such as algal mats and phytoplankton blooms. The model runs also did not account for the burial of seagrasses by sediment, though deposition and incorporation of dredge material into the sediment is included in the model.

The authors recommended that a buffer zone or barrier be utilized between the open-bay unconfined PAs and the nearest seagrass beds to limit the impacts of elevated TSS levels on adjacent plant populations. Model simulations and in situ measurements of an actual dredging event demonstrated that plants located within 500 m of PA 235 were completely buried, and plants that were 700 m from PA 235 were measurably affected by chronic low levels of light for up to nine months following placement. They also recommended that dredging and placement activities at open-water, unconfined PAs be limited to the period between November 1 and February 28 each year to ameliorate TSS impacts on growth. This period is characterized by low (< 20°C) water temperatures and a general dormancy in seagrass metabolism, including photosynthesis and growth. Dredging activities during this dormancy period are likely to impact seagrass populations least, although resuspension of sediments during the peak growth period in spring could result in significant drops in water column transparency and seagrass productivity.

EFFECT OF CLOSING THE GIWW BELOW CORPUS CHRISTI BAY ON EXPENDITURES FOR TRANSPORTATION SERVICE

Fuller and Fellin (1998) conducted an economic analysis to determine the effect on transportation costs to and from the area served by shallow-barge traffic via the GIWW below Corpus Christi, should the GIWW close below Corpus Christi Bay. The analysis was based on examination of four scenarios. The first two (scenarios 1 and 2) compared costs based on existing transportation via the GIWW versus the existing least-cost alternatives that would be available if the GIWW were closed, respectively. In light of a proposal to build a new pipeline to carry refined products to the Lower Rio Grande Valley, the second pair of scenarios (scenarios 3 and 4) compared the costs of transporting refined products only with and without the GIWW, assuming that the pipeline was already in place.

The analysis examined the percentages of various commodities, and their points of origin, transported to the communities (southbound) served by the GIWW below Corpus Christi (Port Mansfield, Harlingen, Port Isabel, and Brownsville) and the percentages of commodities transported from those communities (northbound), and their destinations. Based on these numbers, least-cost methods and costs of alternatives to shallow-barge transport were developed. It was determined that 75% of southbound tonnage was refined petroleum products (80% of which was gasoline). Alternatives examined to determine the least-cost alternatives were oceangoing barge to the Port of Brownsville, rail, and truck.

The authors note certain limitations of the study. One is the assumption that historic origins, destinations, and quantities of shipped goods would remain the same if the GIWW closed. They note that this would likely not be entirely true. They also note that if a competitive transportation environment did not evolve, were the GIWW to be closed, the increase in costs estimated by the analysis would likely be underestimated. The study is, however, strictly an economic study which does not include other resulting problems, such as the increase in air emissions and traffic congestion.

The results of the economic analyses are as follows:

1. Scenario 1 yielded total transportation and transshipment costs equal to $11.41 million versus $22.83 million for Scenario 2. Therefore, closing the GIWW below Corpus Christi Bay, under existing conditions, would roughly double the transportation and transshipment costs of commodities transported by shallow-draft barge via the GIWW, an increase of $11.42 million.
2. The analysis did not provide individual costs for Scenarios 3 or 4. However, the increase in costs associated with Scenario 4 versus Scenario 3 was $5.17 million.

ESTIMATION OF ECONOMIC IMPACTS OF INDUSTRY, SERVICES, RECREATIONAL ACTIVITIES, COMMERCIAL FISHING, AND TOURISM ASSOCIATED WITH THE GIWW IN THE LAGUNA MADRE

Tanyeri-Abur, et al. (1998) estimated the economic impacts of the industries and activities that are affected by the GIWW, for the Laguna Madre region, and the state of Texas. This was done via an impact model, which related these industries and activities to their economic dependence on the GIWW. The categories used in the model are:

I. Industries or activities that depend on barge transportation:
   - petroleum refineries
   - chemical industries
   - oil and gas extraction
   - sand, gravel, and other mining and quarrying
   - ship and boat building and repairing
   - rail, motor vehicle, and water transportation and transportation services

II. Industries or activities that benefit from, or are somewhat dependent on, barge transportation:
   - agriculture (some commodities such as sugar and some grains)
   - heavy construction

III. Industries or activities that use the GIWW and are also dependent on water quality and aesthetics:
   - commercial fishing
   - prepared fish and seafood

IV. Industries or activities that are dependent on water quality and aesthetics:
   - retail, tourism, and related industries

V. Industries or activities that are largely independent of the GIWW:
   - agriculture (ranching, citrus, and other crops).

Because of the size of the economic activity of Nueces County, the report used two input-output models: one for the Lower Laguna Madre Region (Lower LMR), defined as Hidalgo, Cameron, Willacy, Kenedy, and Kleberg counties, and one for the Total Laguna Madre Region (Total LMR), which added Nueces County to those in the Lower LMR. The study area, which in 1995 had about one-fifth of the state's population, is unique in that economic activity is concentrated in the northern (Nueces County) and southern (Cameron and Hidalgo counties) extremes; i.e., 95% of employment for the six counties is in these three. Most of the land along the GIWW through the Laguna Madre is devoted to ranching, crop production, or is vacant of economic activities.

The economic impact analysis in Tanyeri-Abur, et al. (1998) is based on regional economic development theory presented by Richardson (1969). The theory states that "the growth of a region is initiated by and depends primarily on its ability to produce goods and services that are 'exported' from the region." Export industries or sectors include agriculture, mining, manufacturing, non-residential construction, tourism, Federal government, State government, which provide direct impacts. Residentiary industries or sectors are those that "provide goods and services to the export industries ... and to their employees and families." Residentiary industries or sectors include business services, personal services, wholesale services, retail services, financial institutions, local governments, residential construction, and transportation/communications/utilities. The theory perceives that all new income and employment derives from the sale of export goods and services, and therefore, the total income and employment of an area are ultimately derived from "export" industries or sectors. While the report notes that caution should be used in the absolute categorization of local businesses, it also notes that minor misclassifications should not cause significant problems with the analysis.

Table 2 presents direct impacts as estimated final demand (1995) by category, sector, and Laguna Madre region (Tanyeri-Abur, et al. 1998).

TABLE 2

EXPORT INDUSTRIES (SECTOR) ESTIMATED DIRECT IMPACTS

Category	Sector	Lower LMR ($ millions)	Total LMR ($ millions)
I.	Oil extraction, petrochemicals, and transportation	912.54	1,678.24
II.	Heavy construction and some agricultural commodities	225.57	336.28
III.	Commercial fishing and seafood manufacturing	72.35	99.25
IV.	Water related recreation	170.41	297.20
V.	Agriculture	330.44	395.28

These estimated direct impacts were used to estimate the total (direct plus indirect) economic impacts of bay-related industries or sectors on the study area. These results are presented in the following table (Table 3), using the categories noted above, from Tanyeri-Abur et al. (1998).

A similar table was generated for the total economic impacts of bay-related industries or sectors on the state of Texas, with slightly larger values in most categories but smaller in a few.

With data from the Texas Workforce Commission and the U.S. Bureau of the Census (USBOC), the authors determined the total employment and total annual payroll of the study area with (311,973 and $6,203,046, respectively) and without (180,989 and $3,040,283, respectively) Nueces County. These data and those from the table above (Table 2) indicate that 25% and 22% of the employment and personal income, respectively, in the Lower LMR are related to the GIWW and that 20% and 18% of the employment and personal income, respectively, in the Total LMR are related to the GIWW.

TABLE 3

ECONOMIC IMPACTS OF BAY-RELATED INDUSTRIES
(in $ millions)

Region	Category I	II	III	IV	V	Total
Output						
Lower LMR	1,469	274	117	290	563	2,713
Total LMR	3,059	367	168	534	718	4,846
Personal Income						
Lower LMR	342	89	21	113	192	756
Total LMR	668	118	31	205	237	1,258
Value-Added						
Lower LMR	631	147	41	179	321	1,319
Total LMR	1,315	195	59	324	410	2,304
Employment						
Lower LMR	13,185	5,451	1,243	6,605	12,999	39,483
Total LMR	22,909	6,187	1,782	11,615	15,040	57,533

ALTERNATIVES FOR BENEFICIAL USE OF DREDGED MATERIAL

A study was conducted for the EPA, as a member of the ICT, to develop an environmental overview of alternatives for beneficial uses of maintenance material dredged from the GIWW in the Laguna Madre. Two categories of beneficial use were determined to be appropriate: habitat development, including protection of existing habitat, and beach nourishment. One non-beneficial use was included at the request of the EPA: offshore placement at existing Ocean Dredged Material Disposal Sites (ODMDSs). No economics were included in reaching conclusions and practicality of alternatives was included only in broad terms. The report notes that "development and evaluations of alternatives was not for the purpose of selecting a preferred plan of action, or otherwise predetermining the content of the DMMP. All conclusions should be considered as contributing to the building of a frame work or foundation for future project-specific and site-specific planning."

The report presents an environmental overview of the Laguna Madre to provide the background and context for the evaluation of alternatives. The report also summarizes past dredging and placement activities in the Laguna Madre, the physical and chemical characteristics of the dredged material available for beneficial uses, the impacts of current practices, and the characteristics of the ODMDSs.

After use of a screening process, nine beneficial use alternatives were identified and described:

A. nourishing Gulfside beaches,
B. nourishing washover areas,
C. nourishing dredged material islands,
D. extending tidal flats into submerged habitat,
E. extending seagrass beds onto naturally unvegetated lagoon bottoms,
F. restoration of seagrass beds on degraded lagoon bottoms,
G. creating new dredged material islands with levee material from existing islands,
H. creating new dredged material islands using other confining materials, and
I. expanding existing dredged material islands.

Additionally, as noted above, offshore placement in the ODMDSs was examined as a tenth alterative.

Twelve evaluation criteria were described, applied to each alternative, and given a rating of 0, 1, or 2, where 2 indicates more impacts/fewer benefits and 0 indicates fewer impacts/more benefits. The criteria are:

1. benefits to natural habitats,
2. benefits to modified habitats,
3. direct impacts to existing natural habitats,
4. direct impacts to existing modified habitats,
5. impacts of material transport,
6. turbidity impacts,
7. effects on water circulation,
8. potential resource conflicts,
9. limitations imposed by material type,
10. limitations on potential material usage,
11. risks of failure, and
12. level of ongoing effort.

The ratings of the evaluation criteria for the various alternatives were summarized at the end of the exercise. Because of the constraints on potential beneficial uses, primarily from grain-size properties, and the high cost of most beneficial uses addressed in the report, the conclusion of the report was that, unless conventional means were found to be environmentally unacceptable, beneficial use of maintenance material is not likely to be commonplace. The report found Alternative C, nourishing dredged material islands to be the most cost-effective beneficial use alternative, if dredged sands are used. However, the report recommended further study of three alternatives: B – nourishing washover areas, F – restoration of seagrass beds on degraded lagoon bottoms, and G – creating new dredged material islands with levee material from existing islands.

Relative to ocean placement, the study only looked at the suitability of the material to be placed offshore without the need for an additional EIS (which would be required) and did not address the cost or technical feasibility of offshore placement. It did note that pumping via a pipeline for more than 2 miles would require booster pumps, and that pumping over long distances poses environmental concerns.

PIPING PLOVER HABITAT SURVEY OF DREDGED MATERIAL PLACEMENT AREAS IN THE LOWER LAGUNA MADRE

PAs 210–236 are located in the LLM between the Land Cut and the Brownsville Ship Channel. A survey of these placement areas was conducted from February 17 through February 20, 1997 (EH&A, 1997b). The purpose of the study was to determine whether habitat of the Federally and State-threatened piping plover occurs at and near the existing placement areas and to determine whether other members of the maritime shorebird guild were utilizing the placement areas. Because the boundaries of the placement areas are not always rigidly defined, the survey included all potential habitat near each placement area. The survey was performed between cold fronts, so similar weather conditions existed during the 4-day survey period.

Of the 27 placement areas, eight were completely open water and five others were mostly open water. Only 12 placement areas contained substantial amounts (roughly 50% or greater) of emergent land. The survey revealed very little suitable habitat for the piping plover. The authors indicated that PAs 210, 211, 224, and 225 were most likely to be used by piping plovers, as much because their proximity to extensive algal flats as because of the habitat found on the placement areas themselves. PAs 210 and 211 are located near the extensive algal flat area along the south end of the Land Cut and PAs 224 and 225 are near extensive algal flats at the Laguna Atascosa National Wildlife Refuge (LANWR). However, the majority of these four placement areas do not contain suitable habitat which would be used by piping plovers. In general, none of the placement areas were considered important habitat to piping plovers, although many of the emergent placement areas provide rookeries to numerous species of the shorebird guild and other water birds. The report recommends placement of maintenance material on the various emergent islands to be timed to avoid nesting season, if possible.

EFFECTS OF DREDGED MATERIAL ON PIPING PLOVERS AND SNOWY PLOVERS, LOWER LAGUNA MADRE

Original Study

In November 1996, the National Audubon Society and Texas A&M University – Kingsville was contracted to conduct a 17-month survey of piping plover and snowy plover use of winter habitat, monitor their diurnal and nocturnal movements, and document their use of different habitats on a daily and seasonal basis in the LLM (Zonick et al., 1998). The study results were also to indicate possible beneficial uses of the dredged material to enhance or maintain plover habitat near the GIWW. The purposes of the study were to be accomplished mostly by banding and tracking snowy plovers, as a surrogate species, and, if possible, to band and track a few piping plovers. In actuality, most of the birds banded and tracked were piping plovers. Tracking was accomplished by gluing to the piping plovers a 1.2-gram (g) radio transmitter (average lifespan of 8 weeks) and by use of leg bands. Birds were captured with leg-hold noose mats and mist nets, and measured for weight, wing cord, tarsus length, bill length, and estimated furcular fat deposits. Radioed plovers were monitored both from the ground and from the air. In all, 49 piping plovers and 32 snowy plovers were trapped and banded. Radio-transmitters were attached to all piping plovers and to five snowy plovers. One piping plover was captured twice during the project and was fitted with a transmitter both times. When marked plovers were found, date, time, location (GPS), habitat type, distance to water, behavior, and tidal amplitude were noted. Additionally, non-marked roosting plovers were noted and features of the roost habitat, including microhabitat, microhabitat type, distance from water, and tidal amplitude, were recorded. These data were compared to the same types of data from sites 50 feet from the roost site, in a random direction. Additionally, 12 placement areas along the GIWW in the LLM, 12 placement areas along channels other than the GIWW, and five sites with characteristics similar to the placement areas were visited to determine usage by plovers and other members of the flat-nesting guild (FNG).

The body mass of the captured piping plovers ranged from 48 g to 71 g with an average of 54.1 g, while the mass of snowy plovers ranged from 33 g to 50 g with an average of 43.7 g. Furcular fat deposits for both species covered the full range of no fat deposits to excessive fat reserves. All marked plovers used more than two habitat types. All but one plover used both high and low flat habitat with ten using beach habitat and 26 using washover pass habitat.

The winter ranges for the marked piping plovers ranged from 568 to 67,557 acres, with a mean of 12,417 acres and most traveled among widely spaced locations. Twenty-one of the marked piping plovers used both island and mainland sites, with use of the mainland sites apparently linked to the arrival of northers in late fall. After December, mainland site use appeared to have no correlation to the arrival of northers. Only 2% of recordings of marked piping plovers were in or near placement areas and plover use of mainland habitat did not include placement areas.

Zonick et al. (1998) also studied roosting behavior and habitat. Most piping plovers (92.7%) were not roosting when they were relocated. Those found roosting preferred to roost primarily within the high flat habitat near foraging sites, although washover passes and low tidal flats were also used. Piping plovers appeared to roost most often when tides rose above the mean tide line and were observed farther from the water than were foraging plovers. In the LLM, piping plovers normally roost alone or in small flocks of five birds or fewer. Snowy plovers roosted exclusively in the high flat habitat but showed no preference for tide height. The study also indicated that plovers select roost sites based on certain micro-habitat features, such as percent cover of depressions and debris, depression depth, water cover, etc.

The conclusions of Zonick, et al. (1998) were that preserving large tracts of bayshore tidal flats is very important to piping and snowy plovers; washover passes and mainland tidal flats provide critical feeding and roosting sites; most plovers use both mainland and island sites; in the LLM, plovers appeared to prefer mainland sites to beaches as secondary habitat; placement areas do not appear to provide suitable habitat, as evidenced by the low usage of placement areas by wintering plovers; and where placement areas have eroded onto tidal flats and caused a conversion to upland habitat, there has been a decrease in value to plovers. Although none of the placement areas along the GIWW support piping plover or other FNG nests, non-GIWW placement areas and some placement area-like sites were found to support nesting and brood rearing, the location of nests being based on a number of habitat and micro-habitat parameters, e.g., sparse vegetation, above mean high tide, near shallow water, etc. Like EH&A (1997b), Zonick et al. (1998) recommends that dredged material placement not occur during the nesting season for piping plovers or other members of the FNG. Charts showing habitat type; trap site, foraging sites, roosting sites, unknown behavior sites, and nocturnal relocation sites; home range; distance to water; habitat use estimates; and band colors are included in the report for each marked plover.

Final Report

The study conducted by Zonick et al. (1998) between August 1997 and May 1998 was continued and expanded for the 1998 to 1999 field season by three of the five authors, all personnel from the Caesar Kleberg Wildlife Research Institute, Texas A&M-Kingsville. The three authors, Kiel Drake, Katherine Drake, and Jonathan Thompson, also undertook a more-rigorous analysis of the 1997 to 1998 piping plover radio-telemetry data investigating seasonal habitat use, movements, and home range size. Their final report is entitled "The Effects of Dredged material on Piping Plovers and Snowy Plovers Along the Southern Laguna Madre of Texas, Final Report 1997–1999" (Drake et al., 1999).

Drake et al. (1999) conducted the fieldwork for their study from August 15, 1998 through May 15, 1999. Searches were conducted using four-wheel drive vehicles, all terrain vehicles (ATVs), and by foot. Habitat types included placement areas; mudflats (i.e., mainland tidal flats); lower sand flats (i.e., sand flats usually covered by the Laguna Madre and only exposed during low tides); algal flats; and upper sand flats (located between algal flats and secondary dunes), washover areas, and beaches (located between the Gulf of Mexico and the primary dunes). The investigators sought to gather information on habitat use, movements, home range size, roosting habitat (including that of snowy plovers), site fidelity, survival, abundance, and population size. Piping plovers were captured using a modified version of leg-snare traps, weighed, checked for body molt intensity and flight-feather molt, fitted with a 1.2-g radio transmitter, and color banded. The transmitters lasted for approximately 57 days. Altogether, 49 piping plovers were fitted with radio transmitters and monitored between August 10, 1997, and April 25, 1999, with a total of 1,371 relocations, an average of 29.6 relocations per bird. Aerial surveys were used to facilitate nocturnal surveys or when marked birds could not be located on the island.

Habitat Use, Movements, and Home Range Size

Algal flats (50.5%) and lower sand flats (23.2%) were the most commonly used habitat types, followed by washover passes (9.4%), upper sand flats (7.1%), mudflats (5.7%), beaches (2.8%), placement areas (0.8%), and roadside ditches (0.5%). Algal flats were used more during the fall and spring than during the winter as a result of seasonally high tides and increased precipitation that increased invertebrate diversity and abundance during the fall and spring, and lack of regular tidal inundation leading to desiccation of the algal flats in the winter. Conversely, lower sand flats were used more during the winter than in either the fall or spring, largely because tidal inundation rendered them unavailable in the fall and spring. When tidal fluctuations submerged algal flats and upper sand flats on the island and tidal flats adjacent to the mainland, piping plovers were forced to use beaches. Use of beach habitat was most frequent during the fall and only occurred when bayshore habitats were unavailable. It was not used during the winter and was used more in the fall than in the spring. Beaches, however, were always available for foraging, irrespective of the tidal cycle. Use of some habitat types was seasonal: placement areas were utilized only during the winter and spring, while roadside ditches were used only during the fall.

Home range is defined as the area used (95% utilization distribution) during normal activities for feeding and roosting. The 1998–1999 data were analyzed and the 1997–1998 data were re-analyzed using this definition. Mean home range size was 3,117 acres and the mean core home range (50% utilization distribution) was 7,269 acres. Both home range and core home range were smaller during the fall than during the winter. Mean linear distance moved per individual was 10,808 feet, being smaller in the fall (6,280 feet) than both winter and spring (13,764 and 11,933 feet, respectively). Both movement and home ranges increased during the winter when seasonal low tides exposed the lower sand flats, thus increasing habitat availability. Wintering plovers along the southern Laguna Madre did not appear to make extensive movements between roosting and foraging areas, tending to roost in the immediate vicinity of, or within, their primary foraging habitats.

Roosting Habitat

Roosting for this study was defined as non-locomoting (motionless, sitting or standing, often with the head tucked into the scapulars) and included daytime as well as nighttime observations. However, it may have been more accurate to confine roosting to nocturnal observations and refer to the daytime behavior as resting or loafing. Wintering piping plovers spent approximately 20% of the day roosting, while snowy plovers roosted up to 40% of the day.

The majority of the roost sites (65%) occurred on algal flats, followed by upper sand flats (29%). Plovers typically roosted individually or in small flocks facing into the wind (83.4% and 84.8% of the piping and snowy plovers, respectively). The average number of piping plovers per roost site was 4.6, while snowy plovers averaged 3.95 per site. Interspecific roost sites averaged 4.79 piping plovers and 3.84 snowy plovers. Other species found roosting with piping and snowy plovers include the sanderling (*Calidris alba*), dunlin (*Calidris alpina*), western sandpiper (*Calidris mauri*), least sandpiper (*Calidris minutilla*), ruddy turnstone (*Arenaria interpres*), semipalmated plover (*Charadrius semipalmatus*), Wilson's plover (*Charadrius wilsonia*), and black-bellied plover (*Pluvialis squatarola*).

Compared to random plots, both piping plover and snowy plover roost sites had more areal coverage of depressions and debris, deeper depressions, less standing water, and drier substrate. Compared to snowy plover roost sites, piping plover roost sites had less coverage of depressions and debris, shallower depressions, more vegetation, and were closer to water and adjacent vegetation. Seasonally, piping plover roosts had less coverage of depressions during the fall and spring, less debris during winter and spring, shallower depressions during the winter, and wetter substrate during the spring than snowy plover roost sites. The depressions were both natural and manmade (e.g., tire tracks, footprints, etc.).

Plovers roosted within depressions or on the leeward side of debris and oriented into the wind, thus reducing wind penetration into their plumage. Roosting may also reduce the risk of predation, particularly by avian predators such as the peregrine falcon (*Falco peregrinus*). While peregrines generally attack prey in flight, they were observed attacking foraging shorebirds and capturing them as they took flight. The typical reaction of a foraging plover was to flatten itself to the ground and remain in this posture until the peregrine had left. Plovers often foraged within the same habitats in which they roosted; thus, selecting roost sites at the microsite level allows plovers to seek cover and concealment while remaining near or within foraging areas.

Site Fidelity, Abundance, Survival, and Population Size

Piping plover site fidelity was determined by overlaying the 1998–1999 relocations over the 1997–1998 polygons for individual birds with the percentage of 1998–1999 relocations occurring within the 1997–1998 polygons being used to determine fidelity rates. Piping plovers exhibited a high fidelity, with 38 (76%) of the 50 birds banded during the 1997–1998 study being resighted during the 1998–1999 study and 318 (72.3%) of the 440 1998–1999 relocations being within the 1997–1998 polygons. The 1997–1998 season also revealed strong patterns of intra-annual (within-year) fidelity to habitats along the southern Laguna Madre by overwintering piping plovers.

Numbers of piping plovers (and snowy plovers) observed in the study area increased from fall to winter and decreased between winter and spring. Maximum winter counts were larger than the fall and spring counts, with maximum counts of 531 for piping plovers and 285 for snowy plovers. Piping plover flock size ranged from 2 to 307, with the mean winter flock size of 14.93 birds larger than the mean fall flock size of 6.61 and the mean spring flock size of 4.75. The snowy plover flock size ranged from 2 to 54, with fall, winter, and spring flock sizes of 2.02, 3.73, and 3.07, respectively.

All 49 radio-tagged piping plovers survived the wintering season, indicating that overwinter survival is probably higher than reported elsewhere for breeding birds (66% based on birds breeding in the Great Plains). This suggests that population declines are due to low hatching success and brood survival on breeding areas and that winter mortality is probably not a factor contributing to population decline. A mark-recapture model was used to calculate piping plover population size using the re-sightings of color-banded birds and overall counts of piping plovers during the surveys, resulting in an estimated population size of 871 piping plovers using habitats along the southern Laguna Madre. With the current population estimate at 5,500, approximately 16% of the entire piping plover population utilizes habitats associated with the southern Laguna Madre. The entire Texas coast accounts for 55% of birds found during winter censuses.

During the 1998–1999 winter season, a captive-reared piping plover was observed. This was the second sighting of a captive-reared piping plover from the Northern Great Plains USACE recovery program.

Conservation Implications and Management Recommendations

Drake et al. (1999) concluded that disposal of dredged material within leveed impoundments on tidal flats or other methods that disrupt normal tidal regimes will result in a net loss of wintering piping plover habitat and recommended that dredge disposal techniques that alter salinity levels (i.e., creating freshwater marshes) be avoided. Conversely, while these authors found no evidence during the study that unconfined disposal of dredged material within the bay system is harmful to piping plovers, they noted that if seagrass beds are negatively affected by unconfined disposal of dredged material, invertebrate diversity, abundance, and availability to piping plovers may be influenced. They recommended further studies on this issue.

Conversion of mainland tidal flats to dredged material placement areas will result in a net loss of habitat for wintering piping plovers because these areas will eventually become upland habitat. In addition, placement islands have in some cases coalesced over time to form barriers that alter the natural regime of inundation and exposure on adjacent mainland tidal flats that eventually become upland habitat and of no use to piping plovers. Placement areas were little used during the study, which is consistent with findings from other studies (e.g., EH&A, 1993, 1997b). Vehicle tracks or other unnatural depressions may also have adverse affects on the hydrology of tidal flats. If habitat loss results in some piping plovers being forced to utilize suboptimal habitats or alter movement patterns, the overall fitness of wintering piping plovers could decline.